THE JOURNAL of the Acoustical Society of America

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Ear Defenders*

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THE development of successful ear defenders requires adequate solutions to two main problems: (1) the development of a material suitable for ear defenders; and (2) the design and molding of types, shapes, and sizes of ear defenders to provide adequate insulation, consistent with easy insertion, comfort, and positive retention, for two conditions of use. The first condition allows complete closure of the ear canal; the second demands automatic pressure equalization through the ear defender.

The first problem, development of a material suitable for ear defenders, has been met by a specially compounded Neoprene stock which is readily prepared and which cures as quickly and easily as rubber. The cured Neoprene is soft; its Shore Hardness No. 37 is only slightly greater than that of a soft medical rubber, which has a Shore Hardness No. 32.† It is tough; the weight necessary to tear a nicked strip 2 cm long, 1 cm wide, and 0.05 cm thick, cut 0.4 cm across from one edge, is 230 gwt, as compared to 260 gwt for rubber. It is readily stretched; the ratio of stretch to original length for a strip 2 cm long, 1 cm wide, and 0.05 cm thick, stretched by a force of 150 gwt, is 0.30 as compared to 0.33 for rubber; but it regains its original shape immediately with negligible permanent set. It is permanent; ear defenders cured eighteen months ago show no detectable change. It is resistant to ear wax; no appreciable change has occurred when ear defenders made of this material have been worn nightly for three months, whereas rubber ear defenders have become soft and gummy and increased 50–100 percent in size within two weeks. It is resistant to lanolin (which has many of the same ingredients as ear wax), soap, water, and cleaning alcohol. Cured samples submerged in these materials for eight months have shown no appreciable change. It is non-irritating and non-toxic, as two types of test have indicated—"patch

* This paper reports the results of the Research on Ear Defenders carried on during the period November, 1940, to January, 1942, in the Department of Physics of the University of California at Los Angeles, for the National Defense Research Committee. The paper was officially approved for oral presentation, and was read at the May, 1942 meeting of the Society by the first-named author. It has subsequently been approved officially for publication in this Journal.

† Softer stocks were found to be deficient in elasticity, toughness, and permanence—also to be subject to permanent set.

tests" on the skin of the chest and long-continued use in the ears with no ill effects. After being washed with soap and water, the cured Neoprene has no objectionable odor. It is almost flesh-colored and is, therefore, inconspicuous in the ear. It is non-inflammable.

The second problem, that of developing adequate ear defenders to meet the requirements listed, has been met by three types with the same external shape and three sizes for each type. These will be discussed presently.

To serve as a basis for the design of the new ear defenders, a preliminary survey of existing ear defenders was made; all were found deficient in one or more respects. Also a study was made of the characteristics of the ear canal, as determined from many plaster casts of external ear cavities, taken originally as models for hearing-aid insert ear-tips.**

In the course of developing the final ear defenders, some fifty types were designed, molded, and tested. Their diversity is illustrated in Fig. 1, which shows some of the earlier models in the photograph at the right and the section drawings at the left, the drawings being arranged in exactly the same way as the ear defenders are in the photograph at the right. Illustrated are ear defenders with rubber capsules and brass inserts, the rubber capsules having off-center rubber "skirts" (*J*1, *J*2, *J*3). These were fairly satisfactory. Next is shown the *J*4, *J*5, *J*6, *J*7 sequence, each ear defender with a symmetrical rubber capsule (circular cross section) and brass insert, the capsule being filled with a plastic which surrounds the portion of the insert inside the capsule. In the lower section are shown some extreme types: *V*3 and *V*7 models, typifying the extreme double-mass variety with inner and outer brass inserts, set in rubber; *V*10 model with all-rubber fin section and oversize plastic-filled capsule; *V*11 and *V*13 models with no fin section, only rubber capsule and brass insert, but with a wire (*V*11) or Neoprene (*V*13) hook-

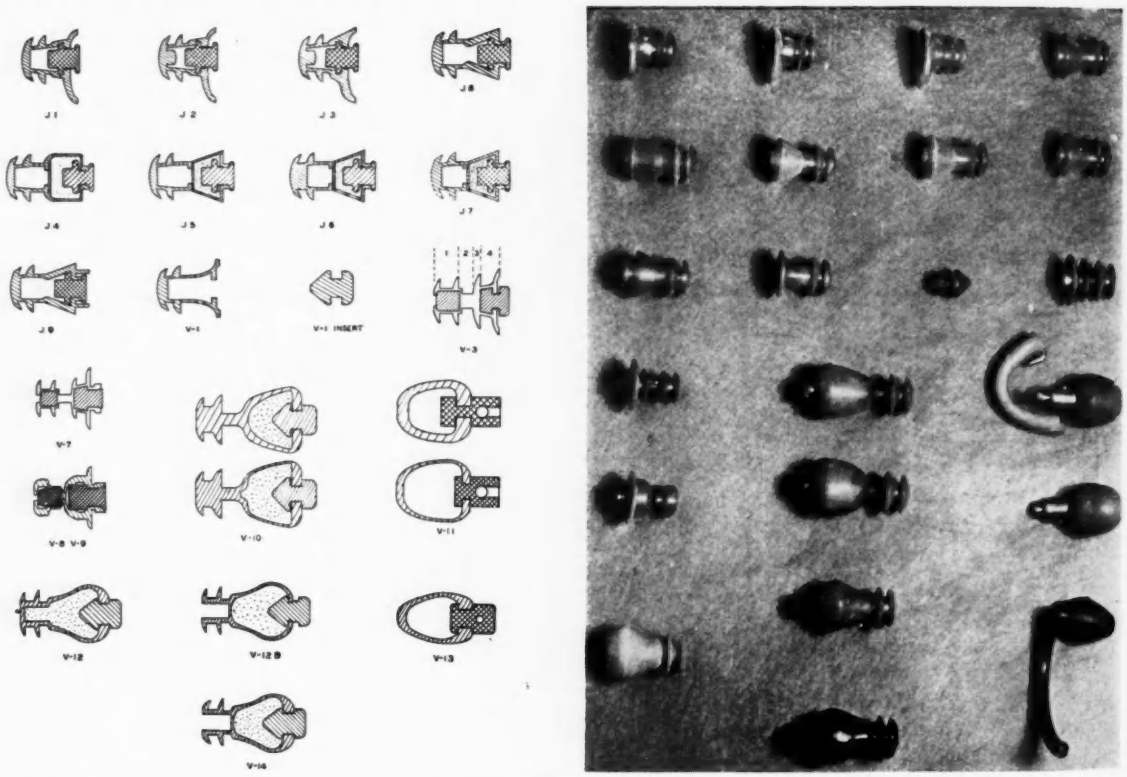

FIG. 1. Section drawings and photograph of ear defenders developed during the earlier portion of the investigation. (The arrangement of the section drawings at the left is exactly the same as that of the ear defenders in the photograph on the right.)

** Measurements were made on thirty plaster casts, carefully selected from 191 casts, to give small, medium, and large size averages, and to give estimates of extremes as to shape among the three sizes.

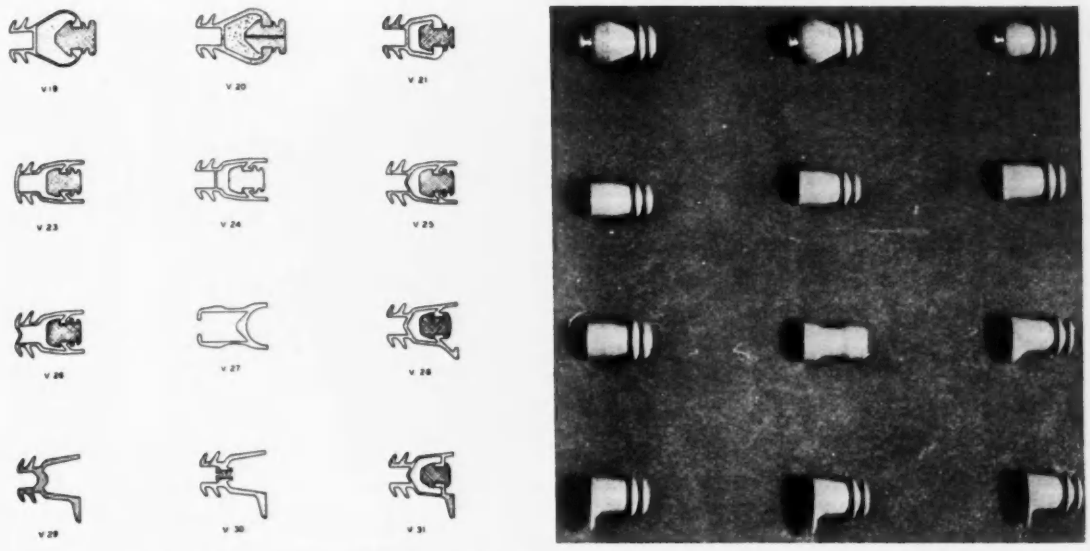

FIG. 2. Section drawings and photograph of ear defenders developed during the later portion of the investigation.

tail to fit in the helix and hold the defender in place.

In Fig. 2 are shown the more conservative models, including the final recommended types. Some of these are extremely simple, being light, all-Neoprene, ear defenders (*V*27 and *V*29).

Tests of the effectiveness of the ear defenders as to insulation against pure tones and speech were made in a free-field room especially built for this purpose. It is a double-shell test chamber, with rockwool and multiple-layer cloth interior treatment. It is situated in a relatively quiet place—quiet enough that the double walls eliminate residual noise for the listener. The absorption of the cloth and rockwool is very high for the frequencies used, and free-field conditions are approximated. The listener sits with his head four feet from the loudspeaker and directly in line with it.

The insulation at each test frequency was determined from the difference in attenuator settings in the linear source system to give thresholds with and without ear defenders in place. These insulations were checked in a few instances by determining the difference in attenuator settings to give 40-phon loudness levels with and without ear defenders. The magnitude of insulation was approximately the same by the threshold and equal loudness methods.

The insulations attained with the widely different types of ear defenders—which one would expect to have markedly different insulations—were surprisingly near to the same value; and none of the better ear defenders gave as high insulations as one would expect from their construction. These two facts indicate that there are limiting factors in the structure of the head and the hearing mechanism which put an upper limit on the possible insulation of ear defenders for a person with normal hearing.

One factor recognized as a possible limitation was the shear compliance of the skin lining of the external ear canal. The question presented itself: would an ear defender have a higher insulation if mounted in a rigid tube without a compliant lining? To test this, an $\frac{11}{32}''$ hole was drilled along the axis of a $2\frac{1}{2}''$ steel bar 9″ long. The hole was enlarged to $\frac{1}{2}''$ diameter for approximately an inch and a half at one end and "insert-sleeves" of brass, ordinary rubber, and Korogel were fitted accurately to the enlarged hole. The inner diameter of each insert-sleeve was $\frac{11}{32}''$, so that it formed a continuous hole with the hole in the steel rod. The hole in the steel rod beyond the insert-sleeve was stuffed with cotton, with variable density of packing, to give an approximately resistive loading to the acoustical transmission system. One tube of a stethoscope was attached at the far end of the rod. Thus the *ear* was used as a detector to determine the insulation of the defenders placed in the insert-sleeves. For a source an electro-

dynamic earphone in a sponge rubber ear cushion was clamped tightly over the end of the bar in which the insert-sleeves and ear defenders were inserted. A loose cotton plug was placed in the small cavity between the protected earphone diaphragm and the ear defender. A test frequency of 250 cycles was used. The insulation was determined by finding the difference in intensity levels required to give a threshold through the stethoscope tube when an ear defender was placed in the insert-sleeve in the rod and when it was absent.

With a brass insert-sleeve, sealed in the steel rod with lanolin to avoid any possible sound leak around the insert-sleeve, there was no appreciable difference between the insulations of a solid brass plug and a *V*29 ear defender (single-septum, all-Neoprene); both insulations were approximately 60 db. With a stiff rubber tube insert-sleeve replacing the brass sleeve, the insulations remained the same. When, however, a Korogel sleeve was used, the insulations dropped to approximately 35 db, but were still nearly the same for brass plug and *V*29 ear defender. These tests indicated that the ear defenders are highly effective in a rigid mounting (although the value of insulation determined, 60 db, may be somewhat too high) and that a mount highly compliant in shear reduces the insulation markedly—reduces it to approximately that obtained for the defenders in the ears, namely, 35 db.

The results thus indicate that the shear compliance of the ear canal skin lining is an important factor in limiting the maximum insulation to be expected from ear defenders.

An attempt was made to determine if this were the final controlling limitation by covering the ears (ear defenders in place) with tightly-sealing ear cushions, loaded with steel plates. No appreciable improvement in insulation resulted. When, however, a heavily padded cloth sack (some ten layers of flannel interlined with cotton batting) was placed completely over the listener's head, covering face and forehead as well as ears, and tightly fastened around the neck (breathing tube from mouth out through back of sack), a considerable increase in insulation resulted at the higher frequencies (2000–8000 cycles)—the frequencies for which the sack was known to be highly absorptive. The increase in insulation was as much as 15 to 18 db at 4000 and 8000 cycles. These results, taken together, indicate that the shear compliance of the ear canal lining, though important, and perhaps controlling when the sound is delivered to the ear through an earphone, is not controlling when the listening is in a free field, with the listener facing the source—rather that some other factor is controlling.

The factor suspected was the vibration of the skull by the air-borne waves striking the forehead and face, with resultant transmission of the vibrations to the fluid of the inner ear and excitation of nerve impulses in that manner.

It has been known for some time that occlusion of the ear canals produces a lowering of the bone-conduction threshold, especially at frequencies up to 2000 cycles, no matter what the means of excitation. Recent experiments (prior, however, to this investigation) by R. S. Gales and one of the present authors (NW)[1] have further established that if occlusion of the canals is complete, variation of the mass of the occluding plug does not cause a corresponding variation in the threshold shift—rather, the threshold shift remains almost constant. This means that any ear defender providing a complete seal makes it more likely that the minute vibrations set up in the skull bones by the sound waves impinging on the forehead and face will be audible. Thus it seems quite probable that, when ear defenders are used, the skull vibrations may be the controlling factor in determining the threshold for a listener in a free sound field.

Further experiments have shown that the bone-conduction threshold shift does not occur for a person with pure conductive impairment caused by middle ear obstructions or fixations. Thus, if the bone vibrations control the threshold when the listeners are using ear defenders in a free sound field, one would expect that the free-field threshold curves of a normal-hearing person and the above-mentioned type of hard-of-hearing person, both taken with optimum-insulation ear defenders in place, would be separated only by an amount equal to the bone-threshold shifts occasioned by the closure of the normal-hearing

[1] R. S. Gales and N. A. Watson, J. Acous. Soc. Am. **14**, 207 (1943).

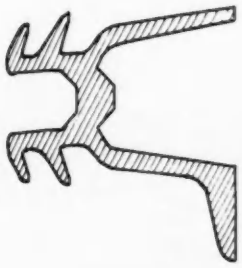

FIG. 3. Type *V*29 ear defender—single-septum, imperforate, all-Neoprene.

person's ear canals—not by an amount indicated as the difference in threshold for the same two people, using ear defenders, when the tests are made with an air-conduction receiver which does not produce bone vibrations. If the hard-of-hearing listener has a slight bone-conduction loss, it must be added to the above-mentioned expected threshold separations.

Such an experiment was tried in the UCLA free-field room after measurements had been made audiometrically. The hard-of-hearing person tested had a large audiometer-measured air-conduction loss (70 db at 125 cycles, and decreasing uniformly to 40 db at 8000 cycles) and a small bone-conduction loss (10–15 db at all frequencies). If the free-field thresholds, with defenders inserted, *are* limited by the bone vibrations induced by the air waves, the free-field threshold curve for this hard-of-hearing person using ear defenders *should* be separated from that of a normal-hearing person using identical ear defenders by approximately 25 to 30 db at the lower frequencies and 10–15 db at the higher frequencies, 10–15 db at each frequency being due to his bone-conduction loss. The actual free-field threshold curve separation (ear defenders used by both listeners) was 25–30 db at the lower frequencies (up to 1000 cycles) and 10–15 db at frequencies above that—which checks the prediction. In contrast to these separations of the curves for free-field tests, the separation of the corresponding curves determined with an air-conduction audiometer receiver was 50 db at the lower frequencies, i.e., up to 1000 cycles.

These results, combined with those of the experiment with the heavy hood, or sack, make it seem very probable that the bone vibrations caused by the air waves are the controlling factor in limiting the insulation possible with ear defenders when used in free-field listening.

With assurance that the maximum possible insulation had been reached, emphasis was placed on other factors in the development of the final model ear defenders. Careful tests were made as to ease of insertion, fit, comfort, and retention of several of the best models, with subjects having wide differences in size and shape of ears. On all bases, the first choice went to an ear defender of external shape very similar to that of the *V*29, *V*30, and *V*31 models (shown in Fig. 2) and internal construction similar to the *V*30. Second choice went to a plastic-filled model similar to the *V*31 ear defender.

On the basis of all tests made, the *V*29 and *V*31 types were chosen as final recommended models for uses in which complete closure of the ear canals is permissible. The *V*29 type, shown enlarged in Fig. 3, is a single-septum, all-Neoprene ear defender—the simplest to manufacture and easiest to keep clean of all the models developed. It has a very satisfactory insulation curve, the insulations lying between 30 and 40 db at all frequencies in the range 62–8000 cycles (see Fig. 9). It can be used for almost all types of ears.

The *V*31 type (illustrated in Fig. 4) was developed for unusual shapes of ears—ears in which any ear defender is so twisted out of shape in trying to fit the ear that an ear defender of the *V*29 type does not give complete closure. The *V*31 is of the double-septum type, with an insert sealed in the outer septum and the space between septa filled with an isoplastic, "tacky," non-elastic plastic, loaded with metallic (or metal oxide) dust. Its normal external shape is the same as that of the *V*29 and *V*30 ear defenders, but because of the "fill" it may be deformed to almost any shape, and hold that shape. Its insulation is approximately the same as that of the *V*29—slightly less, however, at

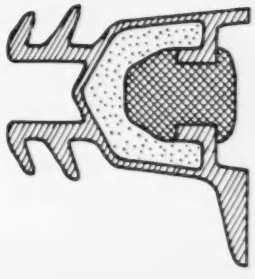

FIG. 4. Type *V*31 ear defender—double-septum, plastic-filled, brass insert, Neoprene capsule.

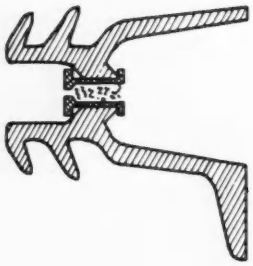

FIG. 5. Type *V*30 ear defender—single-septum, perforate, cotton-packed drilled insert, Neoprene capsule.

low frequencies and slightly greater at high frequencies. This type can be used in almost all ears—many for which the *V*29 is unsatisfactory. Those few ears with extraordinarily peculiar shapes can be fitted only with something like a wax with no covering.

Several methods were tried to provide automatic pressure equalization through the ear defender. It was found that any small hole in the septum or insert—even the tiny hole of a No. 80 drill—ruined the acoustic insulation. Thus it was found necessary to provide the equalization by means of a device with pores of extremely small size. This was accomplished by the drilled, cotton-packed insert of the *V*30 model, illustrated in Fig. 5. A small hole was drilled (No. 60 drill) along the axis of a small spool-shaped insert for almost the total length of the insert; then a very tiny hole was put through the remaining distance with a No. 80 drill. Cotton was packed into the No. 60 section of the hole and the insert sealed into place in the perforation in the single septum of the *V*30 type ear defender. (The *V*30 is otherwise identical with the *V*29.) The degree of packing of the cotton was tested by placing the ear defender in the upper end of a U-tube water manometer and measuring the time necessary for a specified reduction in pressure differential on the two sides of the ear defender to take place through the packed insert. The minimum time of pressure differential reduction to give the maximum possible insulation was determined by listening tests using ear defenders with varying, but known, degrees of packing. The insulation provided by the *V*30 defenders was 25–35 db[2] at all frequencies from 62–8000 cycles. This is less than the insulations of the *V*29 or *V*31 models, but is sufficient to provide a considerable amount of protection, and is coupled with the automatic pressure equalization.

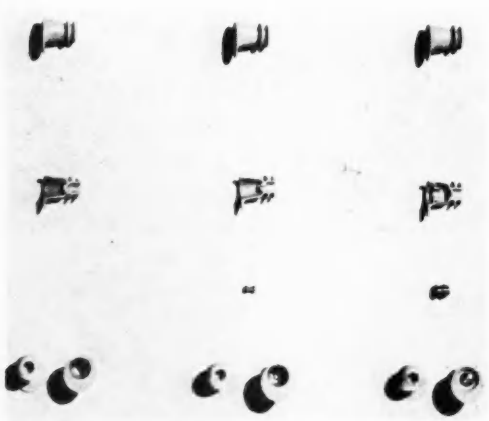

FIG. 6. Types *V*29, *V*30, and *V*31 ear defenders (left to right). For each type is given a side view, opposite end views, and lengthwise section view, with inserts shown separately.

FIG. 7. Correct method of inserting ear defender in left ear.

Photographs of the *V*29, *V*30, and *V*31 ear defenders are shown in Fig. 6 with *V*29 on the left, *V*30 in the center, and *V*31 on the right. For each type are shown: (1) side, (2) cross section, and (3) end views. For the models with inserts, the inserts are shown separately.

In Fig. 7 is illustrated the correct method of insertion of an ear defender. The user reaches over his head with the hand opposite to the ear involved (in the photograph, right hand to left ear), takes the upper edge of the pinna in

[2] In the published abstract of this paper, J. Acous. Soc. Am. **14**, 126A (1942), the insulation of the *V*30 model was erroneously printed as 30–40 db, a repetition of the correct value for the *V*29 model.

FIG. 8. Correct position for ear defender in ear.

his fingers and pulls it upward and backward so as to straighten out the ear canal, then inserts the ear defender with the other hand (left hand in the picture) with the flap of the ear defender in the floor of the concha, pointing backward. In Fig. 8, the ear defender is shown correctly inserted.

For those who find difficulty in removing the ear defenders, a modified design has been developed which is the same as the models described except that the flap at the outer end of the ear defender is longer. (It may be applied to all three types.) A small "handle," attached to the flap and parallel to the axis of the ear defender, has also been suggested.

A comparison of the insulations provided by the ear defenders developed in this investigation is given in Fig. 9. The *V*29 type has a fairly flat insulation curve, lying between 30 and 40 db. The *V*31 model has substantially the same curve but is slightly less effective at the low frequencies and has slightly greater insulations at the high frequencies. The *V*30, with its automatic pressure equalization, has somewhat less insulation, but still 25–35 db over the range shown. Above these are shown the insulations of the commonly used cotton wad. They are negligible except at frequencies above 1000 cycles and are only 15–20 db in the 4000–8000 cycles region. Dry cotton plugs are, therefore, inadequate.

SUMMARY

A material for ear defenders has been developed which is superior to rubber and which the authors believe is entirely adequate for the purpose. Ear defenders have been developed which provide, for most ears, the greatest insulation consistent with easy insertion, positive retention, comfort, and conditions of use.

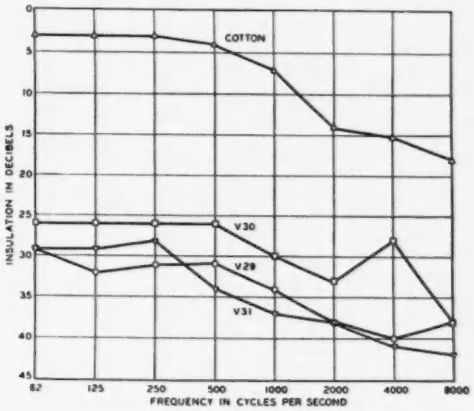

FIG. 9. Insulations of types *V*29, *V*30, and *V*31 ear defenders, compared with each other and contrasted with that of dry cotton wads.

The authors wish to acknowledge their indebtedness and to express their thanks to Dr. L. P. Delsasso for his design and supervision of construction of the double-shell test-room, to Mr. R. S. Gales, Mr. P. S. Veneklasen, and Dr. R. W. Leonard for their able assistance throughout this research, and to Mrs. Ruth B. Watson for her assistance in preparation of the report; also to those other members of the UCLA–NDRC group who assisted as listeners.

Experiments on Dr. Pohlman's Mechanical Hearing Aids*

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(Received September 25, 1943)

IN a previous paper,[1] some experiments on the pellet type of artificial drum were described and interpreted. As a similar investigation has since been carried out on Dr. Pohlman's diaphragm-rod prosthesis, the results may be of interest, especially in view of Dr. Pohlman's recent clinical study on the subject[2] in which a complete bibliography will be found. The prosthesis consists of a thin circular membrane mounted within a cylindrical gelatine tube. A Nylon rod, slightly enlarged at the tip, is firmly fitted into the center of the membrane (cf. Fig. 1).

EXPERIMENTS AND RESULTS

The cochlear function was studied by measuring the electric potential in the cat, the technique being essentially identical with the one described previously.[1] Since a close contact between the tip of the prosthesis and the stapes, as well as elimination of the influence of the stapedius muscle seemed very desirable, head and crura of the stapes were removed. This is easily performed with the aid of a small pair of scissors and a minute hook. Thus, the stapes footplate is completely exposed and well accessible for the tip of the prosthesis which is held in place by a clamp and is readily adjustable. In every case, the cochlea of the ear not being tested was destroyed. A large baffled loudspeaker was used as sound source. The active electrode was again set against the promontorium and not on the round window. In all, 12 cats were used, some preparations being studied in more than one experiment.

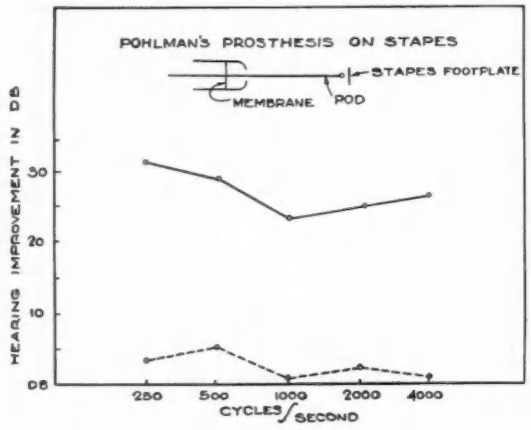

FIG. 1. o————o air-conducted sound;
o- - - - - - -o bone-conducted sound.

The sound source was a loudspeaker whose acoustical output was conducted through a sound tube which terminated as near to the animal's ear as practicable. Representative test frequencies at octave intervals (250, 500, 1000, 2000, 4000 c.p.s.) were generally used. However, in one experiment (No. 4), involving application of pressure to the round window, the response became inconstant at the lower frequencies, presumably because of standing waves. In this case a change in frequency (to 600 and 800 c.p.s., cf. Fig. 3) proved necessary to obtain stable and reproducible results.

For testing bone conduction, a Western Electric receiver was used. It was mounted outside the test room (to avoid electromagnetic disturbance) and connected with the animal's head by means of a brass rod with a Bakelite tip.

In recording the electric response, the reduced ear was first tested. A sound, just intense enough to elicit a reproducible response on the wave analyzer, was generated. After insertion of the prosthesis, the sound was attenuated until the previous response was obtained. This procedure enables us to determine the effect of the prosthesis in db without computation, and facilitates comparison with results in human patients.

* Communication No. 60, prepared with the collaboration of Elmer Culler, Director, Laboratory of Psychology, University of Rochester. These experiments were aided with a grant from the Research Council, American Otological Society.

We are greatly indebted to Dr. Pohlman for furnishing his acoustic probe and a number of his prostheses, as well as for his kind interest in the investigation.

[1] K. Lowy, J. Acous. Soc. Am. **13**, 383 (1942).
[2] A. G. Pohlman, Arch. Otol. **37**, 628 (1943).

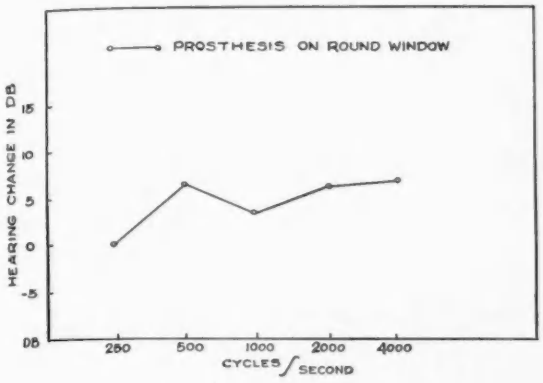

FIG. 2.

Experiment 1

The effect of placing the diaphragm-rod prosthesis upon the stapes footplate was measured in 6 cats by recording the hearing improvement to air-borne sound for 5 frequencies. The results are plotted in Fig. 1 (solid line). The placement of the prosthesis is indicated by the diagram of the same picture. The amount of improvement for each frequency is a mean value which can be shown to be statistically significant according to the method of small samples. They are seen to be about the same for all frequencies tested, the average gain being slightly less than 30 db.

Experiment 2

On four cats, the influence of Pohlman's prosthesis on the response to bone-conducted sound was determined by a method essentially identical to that used for the pellet prosthesis. Placement of the prosthesis was the same as in Experiment 1. The dotted line in Fig. 1 connects the mean values for 5 different frequencies. They are small and do not significantly differ from zero for any value.

Experiment 3

In four animals, the tip of the prosthesis, held in place by a clamp, was applied to the round window. This is easier than application to the stapes footplate since the membrane is larger and easier of access. Care was taken to establish good contact between the tip of the hearing aid and the round window. The promontorium was not touched. Figure 2 shows the average results for 5 frequencies. The gain does not exceed 7 db for any frequency. Statistical analysis shows that only for 4000 cycles is the increase significantly different from zero. The mean of the values for 2000 c.p.s. is approximately the same, but their dispersion was appreciably greater.

Experiment 4

In Experiment 3, the round window proved rather unresponsive to the prosthesis. An effort was therefore made to determine whether the round window, when subjected to external pressure, would modify the action of the prosthesis. On 3 cats, the hearing aid was placed on the stapes by means of a clamp. Simultaneously, a dental pledget was pressed against the round window and held in place by a mosquito clamp. The average improvement, caused by prosthesis *and* pressure against round window concurrently, for four frequencies (600, 800, 2000, 4000 c.p.s.) is plotted in Fig. 3 on dotted line. The effect of the prosthesis alone, as found in Experiment 1, is indicated by the solid line. It seems that conestant pressure applied to the round window does not appreciably interfere with the action of the prosthesis.

Experiment 5

In 5 cats, the effect of Pohlman's acoustic probe was studied. The probe consists of a bamboo rod attached eccentrically to a mica plate. Its construction and clinical application are described in Dr. Pohlman's article. The tip of the probe was placed against the stapes footplate.

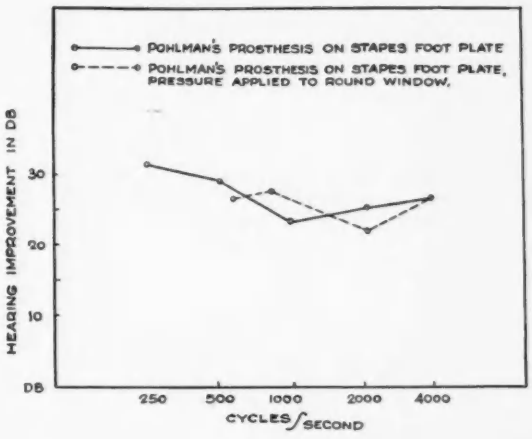

FIG. 3.

The average hearing improvement is shown in Fig. 4 (solid line). It is generally uniform for all frequencies tested. The values obtained are somewhat smaller than those for the prosthesis but still over 20 db and statistically significant.

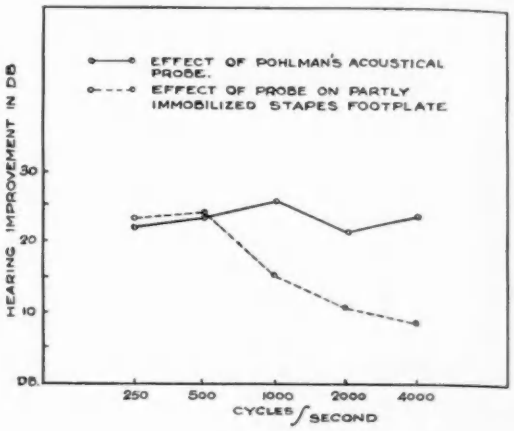

FIG. 4.

Experiment 6

An attempt was made to study the effect of the acoustic probe on ears with partially immobilized stapes. In four out of the five animals used in Experiment 5, the entrance of the oval window was filled with melted paraffin which was allowed to harden before the probe was applied. The paraffin layer thus obtained is about 1.5 mm thick, and sticks firmly to the bone. Covering the stapes completely, it restricts the free mobility of the footplate. After preparing the ear as described, the cochlear response was recorded with and without acoustical probe. The average improvement for 5 frequencies is shown by the dotted line of Fig. 4. The values for higher frequencies are considerably smaller than those observed with normal mobility of the stapes. However, they are still appreciable and differ significantly from zero. The acoustic probe thus proves to be quite effective, in spite of reduced mobility of the stapes.

DISCUSSION

Experiment 1 shows that the Pohlman prosthesis, when applied to the stapes, is an effective hearing aid. Comparison of Fig. 1 with Fig. 3 of the previous paper[1] reveals that it is superior to the cotton pellet type of artificial drum. This is in agreement with clinical experience. However, the improvement of the cochlear function as seen in Fig. 1 differs somewhat from that found in human patients. In the first place, it is not as large for middle and higher frequencies (cf. Fig. 18 of Pohlman's paper[2]); secondly, it is more uniform since there is increased response for low frequencies as well. The human type of response (gain for high tones with much less gain for low tones) is certainly more desirable for improved understanding of speech. The type of hearing response as found in Experiment 1 (approximately uniform improvement for all frequencies tested) resembles the results obtained by using a telephone probe on humans (cf. Pohlman's paper,[2] Fig. 13). The question arises how this discrepancy is to be accounted for. From the acoustical standpoint one might suggest that application of the prosthesis in animal experiments differs somewhat from its use in human subjects. Pohlman fits the capsule of the prosthesis tightly into the outer meatus, thereby creating an additional closed air chamber, similar to the intact middle ear. In the animal experiment, this special feature cannot be duplicated since the middle ear has to be exposed for removal of ossicles and the bulla must be opened for electric recording. Now, it is known that the presence of an enclosed air space has definite influence on the frequency response of the vibrating membrane. This fact is used in the construction of cabinet loudspeakers (cf. Olson,[3] Fig. 7.10). By coupling the loudspeaker membrane with a closed air chamber, undesirable low frequency response is partly suppressed. The same effect is observed when the prosthesis is inserted into a human ear. Assuming that both results are due to the same cause, one would predict uniform hearing improvement without suppression of low frequency in man if the telephone probe or acoustical probe is used, since neither of these creates a closed air chamber. It seems that this actually happens. (Cf. Pohlman's paper,[2] p. 638.)

Experiment 2 shows that hearing of bone-conducted sound is not improved by the diaphragm-rod prosthesis. This effect would be

[3] H. F. Olson, *Acoustical Engineering* (D. Van Nostrand Company, New York, 1940).

anticipated since changes in the sound-conducting apparatus alone never lead to any appreciable impairment of bone conduction.

In Experiment 3, the prosthesis was applied to the round window. This can be done precisely since the membrane is sufficiently large and easily accessible.[4] Without exception, the improvement of hearing was practically negligible. This is an unexpected result especially in view of Pohlman's experience on humans (cf. Fig. 14 of Pohlman's paper[2]). It seems that, at least in the set-up of Experiments 1 and 3, the two windows are not functionally equivalent. Direct transmission of vibration from the rod to the round window is not nearly so effective as transmission through the oval window. On the other hand, Experiment 4 shows that interference with free mobility of the round-window membrane does not affect the hearing improvement obtained by application of the rod to the stapes. Both Experiments 3 and 4 thus seem to indicate that under certain conditions sound transmission through the oval window is of primary importance for hearing, whereas the condition of the round window plays only a secondary role. Discussion of this problem would require a more complete investigation of the function of the round window, which is not proposed in the present paper.

Experiment 5 demonstrates that Pohlman's acoustic probe acts similiarly to his prosthesis. Again, there was rather uniform improvement throughout the frequency range tested. This seems to be analogous to the experience on human patients.

[4] The tip of the prosthesis was much smaller than the area of the secondary membrane, bulging it slightly inwards.

Experiment 6 was performed on some of the animals used for the study of the acoustical probe, chiefly in view of its possible clinical implication. In fenestration operations in man, with a view to improving otosclerosis, the region of the oval window is sometimes made more accessible by removal of the incus (cf. Lempert[5]). After fenestration, especially if the result of the operation has not been entirely satisfactory, one might want to try Dr. Pohlman's prosthesis to achieve some additional hearing improvement. The question arises whether the immobilization of the stapes in otosclerosis makes the acoustical probe completely ineffective. According to Experiment 6, this is not quite the case, and clinical experiments on fenestrated patients may be justified, since some useful gain in hearing may be obtained.

SUMMARY

1. Animal experiments indicate that Dr. Pohlman's prosthesis is an effective hearing aid if applied to the region of the stapes.

2. Bone-conducted sound is not enhanced by the hearing aid.

3. Direct application of the prosthesis to the round window has no appreciable effect on the cochlear response.

4. Intensive pressure applied to the round window while the prosthesis is attached to the stapes does not interfere with the action of the hearing aid.

5. The acoustic probe has essentially the same effect as the prosthesis.

6. Partial immobilization of the stapes reduces, but does not eliminate, the effect of the acoustic probe

[5] J. Lempert, Arch. Otol. **34**, 880 (1941).

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Response of a Linear Rectifier to Signal and Noise

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WHEN the input to a rectifier contains both signal and noise components, the resultant output is a complicated non-linear function of signal and noise. Given the spectra of the signal and noise input waves, the law of rectification, and the transmission characteristics of the input and output circuits of the rectifier, it should, in general, be possible to describe the spectrum of the resultant output wave. Before discussing the solution of the general problem, we shall derive some results of a simpler nature, which do not require a consideration of the distribution of the signal and noise energies as functions of frequency.

I. DIRECT-CURRENT COMPONENT OF OUTPUT

A quantity of considerable importance is the average value of the output amplitude. This is the quantity which would be read by a direct-current meter. Calculation of the average or d.c. response can be performed in terms of the distribution of instantaneous output amplitudes in time. The distribution of output amplitude can be computed from the distribution of instantaneous input amplitudes and the law of rectification.

As an example, we shall compute the average current obtained from a linear rectifier when the input to the rectifier consists of a sinusoidal signal with random noise superposed upon it. The probability density function of the signal voltage is first determined, and the result given in (3). The corresponding probability density for the voltage of the noise is well known and is given in (4). The distribution of occurrence of the resultant instantaneous amplitudes of the combined noise and signal voltages is then computed by the rules of mathematical probability, and the result is shown in (7). The assumption that the rectifier is linear then leads directly to an integral which yields the average current obtained from the rectifier.

Let the signal voltage E_s be given by

$$E_s = P_0 \cos \omega t. \tag{1}$$

The possible angular values of ωt are uniformly distributed throughout the range 0 to 2π. The range E_s to E_s+dE_s corresponds to the range of values of ωt comprised in the interval.

$$\arccos \frac{E_s}{P_0} < \omega t < \arccos \frac{E_s+dE_s}{P_0}. \tag{2}$$

The angular width of this interval is $(P_0^2-E_s^2)^{-\frac{1}{2}}dE_s$. There are two such intervals in the range $0<\omega t<2\pi$. Values of E_s outside the range $-P_0$ to P_0 do not exist. Hence, the probability that the signal voltage lies in the interval dE_s at any particular E_s is given by

$$\Phi_s(E_s)dE_s = \begin{cases} 0, & |E_s| > P_0 \\ 2(P_0^2-E_s^2)^{-\frac{1}{2}}dE_s/2\pi, & |E_s| < P_0 \end{cases} dE_s. \tag{3}$$

Random noise as discussed in this section may be characterized by the fact that the instantaneous amplitudes are normally distributed in time; that is, if $\Phi_n(z)dz$ is the probability that the noise amplitude lies in the amplitude interval of width dz at z,

$$\Phi_n(z) = \frac{1}{\sigma(2\pi)^{\frac{1}{2}}} \exp(-z^2/2\sigma^2), \tag{4}$$

where σ is the root mean square noise amplitude. The mean noise power dissipated in unit resistance is given by $W_n=\sigma^2$. The corresponding mean signal power is given by $W_s=P_0^2/2$. Let $\Phi_r(z)$ represent the probability density function of the instantaneous sum of the signal and noise amplitudes. Then

$$\Phi_r(z)dz = dz\int_{-\infty}^{\infty} \Phi_s(\lambda)\Phi_n(z-\lambda)d\lambda, \tag{5}$$

or

$$\Phi_r(z) = \frac{1}{\pi\sigma(2\pi)^{\frac{1}{2}}} \int_{-P_0}^{P_0} \frac{\exp[-(z-\lambda)^2/2\sigma^2]d\lambda}{(P_0^2-\lambda^2)^{\frac{1}{2}}}. \tag{6}$$

By the substitution $\lambda = P_0 \cos\theta$, we may convert the integral to the form

$$\Phi_r(z) = \frac{1}{\pi\sigma(2\pi)^{\frac{1}{2}}} \int_0^{\pi} \times \exp\left[-(z - P_0\cos\theta)^2/2\sigma^2\right] d\theta. \quad (7)$$

Suppose we insert a half-wave linear rectifier in series with the source of signal and noise, so that the current I is given in terms of the resultant instantaneous voltage E by

$$I = \begin{cases} 0, & E<0 \\ \alpha E, & E>0 \end{cases}. \quad (8)$$

Then the average value of current flowing in the circuit is

$$\bar{I} = \alpha \int_0^{\infty} z\Phi_r(z)\,dz = \frac{\alpha}{\pi\sigma(2\pi)^{\frac{1}{2}}} \int_0^{\infty} z\,dz \int_0^{\pi} \times \exp\left[-(z - P_0\cos\theta)^2/2\sigma^2\right] d\theta. \quad (9)$$

The value of this integral is shown in Appendix I to be

$$\bar{I} = \alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}} \exp\left(-W_s/2W_n\right)\left\{ I_0(W_s/2W_n) + \frac{W_s}{W_n}\left[I_0\left(\frac{W_s}{2W_n}\right) + I_1\left(\frac{W_s}{2W_n}\right)\right]\right\}. \quad (10)$$

This form is particularly convenient for calculation since Watson's *Theory of Bessel Functions*, Table II, gives $e^{-z}I_0(z)$ and $e^{-z}I_1(z)$ directly.

Limiting forms of this equation may be expressed in terms of series in powers of W_s/W_n when the signal power is small compared with the noise power and in powers of W_n/W_s when the noise power is small compared with the signal power. The ascending series for small signal is:

$$\bar{I} = \alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\left[1 + \frac{1}{2(1!)^2}\frac{W_s}{W_n} + \frac{1(-1)}{2^2(2!)^2}\left(\frac{W_s}{W_n}\right)^2 + \frac{1(-1)(-3)}{2^3(3!)^2}\left(\frac{W_s}{W_n}\right)^3 + \cdots\right] = \alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}} {}_1F_1\left(\frac{-1}{2};\ 1;\ \frac{-W_s}{W_n}\right). \quad (11)$$

The asymptotic series, which is available for computation when the signal is large, is

$$\bar{I} \sim \frac{\alpha(2W_s)^{\frac{1}{2}}}{\pi}\left[1 + \frac{(-1)^2 W_n}{1!4W_s} + \frac{(-1)^2\cdot 1^2}{2!}\left(\frac{W_n}{4W_s}\right)^2 + \frac{(-1)^2\cdot 1^2\cdot 3^2}{3!}\left(\frac{W_n}{4W_s}\right)^3 + \frac{(-1)^2\cdot 1^2\cdot 3^2\cdot 5^2}{4!}\left(\frac{W_n}{4W_s}\right)^4 + \cdots\right]. \quad (12)$$

Curves of $\bar{I}$ have been plotted in three ways. Figure 1 shows the ratio of $\bar{I}$ to $\bar{I}_{s0} = \alpha P_0/\pi$, the

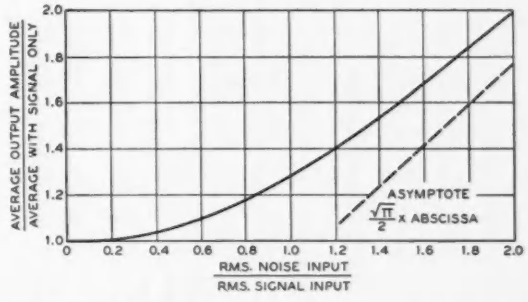

FIG. 1. Variation of direct-current component in response of linear rectifier with ratio of noise input to signal input.

average current in the absence of noise, as a function of ratio of r.m.s. noise input to r.m.s. signal input. Figure 2 shows the ratio of $\bar{I}$ to $\bar{I}_{n0} = \alpha\sigma/(2\pi)^{\frac{1}{2}}$, the average current in the absence of signal, as a function of ratio of r.m.s. signal input to r.m.s. noise input. Figure 3 shows the increment in d.c. power output in decibels as varying amounts of noise expressed in decibels relative to the signal are added. The corresponding result for power addition is given for comparison.

II. SPECTRUM OF OUTPUT

A much more powerful method of attack on this problem is obtained by the use of multiple Fourier series. In this section we shall use Fourier analysis to obtain not only the direct-current output of the rectifier, but also the spectral distribution of the sinusoidal components in the output of the rectifier. We repre-

sent the input spectrum by

$$E = P_0 \cos p_0 t + \sum_{n=1}^{N} P_n \cos p_n t. \qquad (13)$$

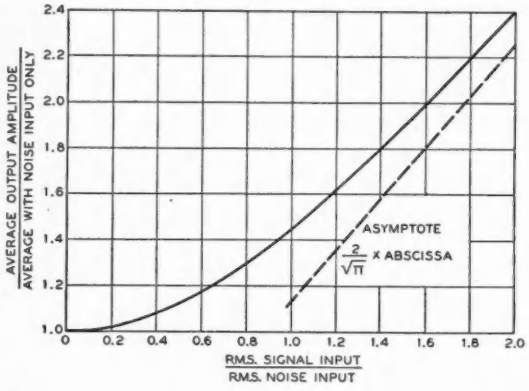

FIG. 2. Variation of direct-current component in response of linear rectifier with ratio of signal input to noise input.

This representation is more general than that given by (4) in that a frequency spectrum as well as an amplitude distribution is defined; it may be shown that the probability density for the sum of N sinusoidal waves with incommensurable frequencies approaches (4) when N is large. The first term represents the sinusoidal signal; the mean power which would be dissipated by this signal in unit resistance is

$$W_s = P_0^2/2. \qquad (14)$$

The noise is represented by a large number N of sinusoidal components with incommensurable frequencies (or commensurable frequencies with random phase angles) distributed along the frequency range f_1 to f_2 in such a way that the mean noise power in band width Δf is:

$$w(f)\Delta f = \tfrac{1}{2} \sum_{k=\nu(f-f_1)}^{\nu(f+\Delta f-f_1)} P_n^2 = \nu \Delta f P^2(f)/2. \qquad (15)$$

Here ν is the number of components per unit band width and $P(f)$ represents the amplitude of a component in the neighborhood of frequency f. Note also that the mean total noise input power W_n is given by

$$W_n = \int_0^\infty w(f)df = \frac{\nu}{2} \int_0^\infty P^2(f)df. \qquad (16)$$

The linear rectifier is specified by the current-voltage relationship (8), which is equivalent to

$$I = -\frac{\alpha}{2\pi} \int_C e^{iEz} \frac{dz}{z^2}, \qquad (17)$$

where C is an infinite contour going from $-\infty$ to $+\infty$ with an indentation below the pole at the origin. We may expand I in the multiple Fourier series[1]

$$I = \sum_{m_0=0}^{\infty} \sum_{m_1=0}^{\infty} \cdots \sum_{m_N=0}^{\infty} a_{m_0 m_1 \cdots m_N} \times \cos m_0 x_0 \cos m_1 x_1 \cdots \cos m_N x_N, \qquad (18)$$

where

$$x_k = p_k t, \quad k = 0, 1, 2, \cdots N; \qquad (19)$$

$$a_{m_0 m_1 \cdots m_N} = \frac{\epsilon_{m_0}\epsilon_{m_1}\cdots\epsilon_{m_N}}{\pi^{N+1}} \int_0^\pi dx_0 \int_0^\pi dx_1 \cdots \times \int_0^\pi I \cos m_0 x_0 \times \cos m_1 x_1 \cdots \cos m_N x_N dx_N; \qquad (20)$$

$$\epsilon_j = \begin{cases} 2, & j \neq 0 \\ 1, & j = 0 \end{cases}. \qquad (21)$$

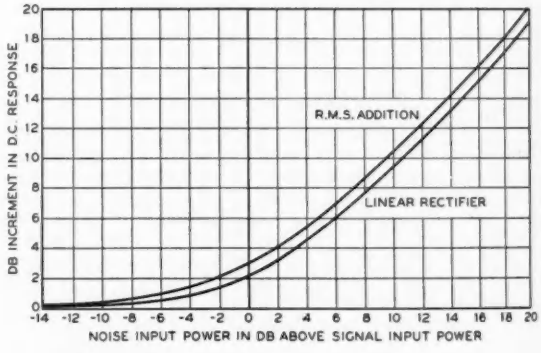

FIG. 3. Variation of direct-current component expressed in decibels, showing comparison between linear rectification and power addition of signal and noise.

The response of the rectifier is thus seen to consist of all orders of modulation products of signal and noise. In a typical case of interest the band of input frequencies is relatively narrow and

[1] W. R. Bennett and S. O. Rice, Phil. Mag. [7], 18, 422–424 (1934). The present application represents an extension to N variables of the theory there given for two.

centered about a high frequency while the output band includes only low frequencies. In such a case the important components in the output are the beats between signal and noise components and between noise components. The d.c. component is present in the output only if the pass band of the system actually includes zero frequency; we have already computed its value in Section I, but we will derive it again by the method used here as a check.

The amplitude of the d.c. component is in fact:

$$a_{00\cdots0}=-\frac{\alpha}{2\pi}\int_C \frac{J_0(P_0z)\prod_{n=1}^{N}J_0(P_nz)}{z^2}dz, \quad (22)$$

on substitution of the expression for E in the integral representation of I, substituting the result in (20), and interchanging the order of integration. When N is large P_n is small; hence the principal contribution to the integral occurs near small values of z, where $J_0(P_nz)$ is nearly equal to unity, since the product of a large number of factors, all less than unity, will be small indeed unless each factor is only slightly less than unity. We therefore replace $J_0(P_nz)$ by a function which coincides with it near $z=0$ and goes rapidly to zero as we depart from this region. Such an approximation (Laplace's process[2]) is

$$J_0(P_nz)\doteq\exp(-P_n^2z^2/4), \quad (23)$$

which is correct for the first two terms in the Taylor series expansion near $z=0$. Therefore, when P_n approaches zero as N approaches infinity,

$$a_{00\cdots0}=\bar{I}=-\frac{\alpha}{2\pi}\int_C J_0(P_0z)\times\exp\left(-\sum_{n=1}^{N}P_n^2z^2/4\right)\frac{dz}{z^2}$$

$$=-\frac{\alpha}{2\pi}\int_C J_0(P_0z)\exp(-W_nz^2/2)\frac{dz}{z^2}. \quad (24)$$

The contour integral cannot be replaced by a real integral directly because the integrand goes to infinity at the origin. However, since

$$\frac{J_0(u)}{u^2}=-\frac{J_1(u)}{u}-\frac{d}{du}\frac{J_0(u)}{u}, \quad (25)$$

$$\frac{J_0(Pz)}{z^2}=-\frac{J_1(Pz)}{P^2z^2}-\frac{d}{d(Pz)}\frac{J_0(Pz)}{Pz}=-\frac{J_1(Pz)}{P^2z^2}-\frac{1}{P^2}\frac{d}{dz}\frac{J_0(Pz)}{z}, \quad (26)$$

we can substitute (26) in the integral and perform an integration by parts to give the result.

$$\bar{I}=\frac{\alpha}{\pi}\int_0^\infty e^{-W_nz^2/2}\left[\frac{P_0J_1(P_0z)}{z}+W_nJ_0(P_0z)\right]dz$$

$$=\alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\left[{}_1F_1\left(\frac{1}{2};1;-\frac{W_s}{W_n}\right)+\frac{W_s}{W_n}{}_1F_1\left(\frac{1}{2};2;-\frac{W_s}{W_n}\right)\right] \quad (27)$$

by Hankel's formula.[3] But it may be shown that (see Appendix II)

$${}_1F_1(\tfrac{1}{2};1;-u)=e^{-u/2}I_0\left(\frac{u}{2}\right), \quad (28)$$

$${}_1F_1(\tfrac{1}{2};2;-u)=e^{-u/2}[I_0(u/2)+I_1(u/2)]. \quad (29)$$

Hence,

$$\bar{I}=\alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\exp(-W_s/2W_n)\left\{I_0(W_s/2W_n)+\frac{W_s}{W_n}[I_0(W_s/2W_n)+I_1(W_s/2W_n)]\right\}, \quad (30)$$

which is identical with the result of Section I, noting that $\sigma=(W_n)^{\frac{1}{2}}$. We point out that a resistance-capacity coupled amplifier will not pass this component since there is no transmission at zero frequency.

The amplitude of the typical difference product

[2] G. N. Watson, *Theory of Bessel Functions* (Cambridge, 1922), p. 421.

[3] See G. N. Watson, reference 2, p. 393. As pointed out by Watson, in a footnote, the difficulty with singularities at the origin could be avoided by expressing Hankel's formula in terms of a contour integral instead of an ordinary integral along the real axis. This procedure would lead directly to the hypergeometric function given in (11).

between the signal and the nth noise component is

$$A_{sn}=\tfrac{1}{2}a_{100\cdots010\cdots0}$$

$$=\frac{\alpha}{\pi}\int_C dz\frac{J_1(P_0z)J_0(P_1z)J_0(P_2z)\cdots \times J_1(P_nz)\cdots J_0(P_Nz)}{z^2}. \quad (31)$$

Using the same process as before, we replace $J_1(P_nz)$ by

$$J_1(P_nz)\doteq\frac{P_nz}{2}\exp(-P_n^2z^2/8) \quad (32)$$

and obtain in the limit as N becomes indefinitely large

$$A_{sn}=\frac{\alpha P_n}{\pi}\int_0^\infty\frac{J_1(P_0z)}{z}\exp(-W_nz^2/2)dz$$

$$=\frac{\alpha P_n}{2}\left(\frac{W_s}{\pi W_n}\right)^{\frac{1}{2}}{}_1F_1\left(\frac{1}{2};2;-\frac{W_s}{W_n}\right)$$

$$=\frac{\alpha P_n}{2}\left(\frac{W_s}{\pi W_n}\right)^{\frac{1}{2}}\exp(-W_s/2W_n)$$

$$\times\left[I_0\left(\frac{W_s}{2W_n}\right)+I_1\left(\frac{W_s}{2W_n}\right)\right]. \quad (33)$$

Relations between the ${}_1F_1$ function and Bessel functions are discussed in Appendix II.

The shape of the spectrum of the beats between p_0 and the noise input evidently consists of the superposition of the noise spectra above and below p_0, so that if we write $w_{sn}(f)\Delta f$ for the mean energy from this source in that part of the filter output lying in the band of width Δf at f,

$$w_{sn}(f)\Delta f=\frac{\nu\Delta f}{2}[(A_{sn}^+)^2+(A_{sn}^-)^2], \quad (34)$$

$$A_{sn}^+=[A_{sn}]_{p_n=p_0+2\pi f}, \quad (35)$$

$$A_{sn}^-=[A_{sn}]_{p_n=p_0-2\pi f}, \quad (36)$$

$$P_n=\left[\frac{2w(f_n)}{\nu}\right]^{\frac{1}{2}}, \quad (37)$$

$$w_{sn}(f)=\frac{\alpha^2W_s}{4\pi W_n}\exp(-W_s/W_n)\times\left[I_0\left(\frac{W_s}{2W_n}\right)+I_1\left(\frac{W_s}{2W_n}\right)\right]^2\times[w(f_0+f)+w(f_0-f)]. \quad (38)$$

The total noise from this source in the output of a particular filter of transfer admittance $Y(f)$ is obtained by integrating $w_{sn}(f)\,Y(f)df$ throughout the band of the filter. In the particular case in which the original band of noise is symmetrical about f_0 and occupies the range f_0-f_a to f_0+f_a and an ideal low pass filter cutting off at $f=f_a$ is used in the rectifier output, the total noise output from beats between signal and noise is

$$W_{sn}=2\int_0^{f_a}w_{sn}(f)df=\frac{\alpha^2W_s}{4\pi}\exp(-W_s/W_n)\times[I_0(W_s/2W_n)+I_1(W_s/2W_n)]^2. \quad (39)$$

Next we shall calculate the spectrum of the energy resulting from beats between individual noise components. We write

$$A_{nn}=\tfrac{1}{2}a_{00\cdots010\cdots010\cdots0}$$

$$=\frac{\alpha}{\pi}\int_C dz\frac{J_0(P_0z)J_0(P_1z)\cdots J_1(P_rz)\cdots \times J_1(P_sz)\cdots J_0(P_Nz)}{z^2}$$

$$=\frac{\alpha P_rP_s}{2\pi}\int_0^\infty J_0(P_0z)\exp(-W_nz^2/2)dz$$

$$=\frac{\alpha P_rP_s}{2(2\pi W_n)^{\frac{1}{2}}}{}_1F_1\left\{\frac{1}{2};1;-\frac{W_s}{W_n}\right\}$$

$$=\frac{\alpha P_rP_s}{2(2\pi W_n)^{\frac{1}{2}}}\times\exp(-W_s/2W_n)I_0(W_s/2W_n). \quad (40)$$

To find the resulting spectrum $w_{nn}(f)df$ produced at f by the resultant of all such components, we note that we may sum over all components by beating each component of the primary band with the frequency f above it and adding the resultant power values. The result is

$$w_{nn}(f)=\frac{\alpha^2}{4\pi W_n}\exp(-W_s/W_n)I_0^2(W_s/2W_n)\times\int_0^\infty w(\lambda)w(\lambda+f)d\lambda. \quad (41)$$

In the particular case of a flat band of energy

extending from f_1 to f_2,

$$\int_0^\infty w(\lambda)w(\lambda+f)d\lambda=\int_{f_1}^{f_2-f}\frac{W_n^2}{(f_2-f_1)^2}d\lambda$$

$$=\frac{f_2-f_1-f}{(f_2-f_1)^2}W_n^2,\quad 0<f<f_2-f_1,\quad (42)$$

$$w_{nn}(f)=\frac{\alpha^2(f_2-f_1-f)W_n}{4\pi(f_2-f_1)^2}$$

$$\times\exp(-W_s/W_n)I_0^2(W_s/2W_n),$$

$$0<f<f_2-f_1.\quad (43)$$

The total mean power of this type lying in the band 0 to f_b is

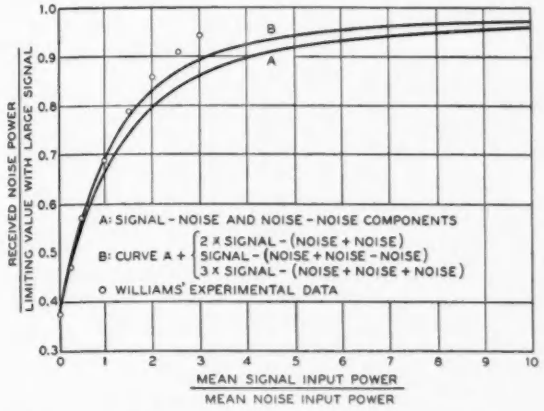
RECEIVED NOISE POWER
LIMITING VALUE WITH LARGE SIGNAL
A: SIGNAL - NOISE AND NOISE - NOISE COMPONENTS
B: CURVE A + { 2 × SIGNAL - (NOISE + NOISE) / SIGNAL - (NOISE + NOISE - NOISE) / 3 × SIGNAL - (NOISE + NOISE + NOISE) }
o WILLIAMS' EXPERIMENTAL DATA
MEAN SIGNAL INPUT POWER
MEAN NOISE INPUT POWER

FIG. 4. Calculated noise power in audio band of output of linear rectifier when noise and signal are applied in a relatively narrow high frequency band. The direct-current component is excluded.

$$W_{nn}(f_b)=\int_0^{f_b}w_{nn}(f)df$$

$$=\frac{\alpha^2W_n(f_2-f_1-f_b/2)f_b}{4\pi(f_2-f_1)^2}$$

$$\times\exp(-W_s/W_n)I_0^2(W_s/2W_n),\quad (44)$$

provided $f_b<f_2-f_1$. The spectrum is confined to the region $0<f<f_2-f_1$. If f_b is equal to f_2-f_1 so that the output filter passes all the noise of this type, we have

$$W_{nn}(f_2-f_1)=W_{nn}$$

$$=\frac{\alpha^2W_n}{8\pi}\exp(-W_s/W_n)I_0^2(W_s/2W_n).\quad (45)$$

This result seems to hold approximately for a considerable range of input spectra. For example, if we assume that the original noise is shaped like an error function about f_0, i.e.,

$$w_n(f)=W_n(a/\pi)^{\frac{1}{2}}\exp[-a(f-f_0)^2]\quad (46)$$

with f taken from $-\infty$ to $+\infty$ with small error for large f_0,

$$\int_{-\infty}^{\infty}w(\lambda)w(\lambda+f)d\lambda$$

$$=W_n^2(a/2\pi)^{\frac{1}{2}}\exp(-af^2/2)\quad (47)$$

$$\int_0^\infty df\int_{-\infty}^{\infty}w(\lambda)w(\lambda+f)d\lambda=W_n^2/2,\quad (48)$$

which is in agreement with (45).

The output of a half-wave linear rectifier contains fundamental components and all even order modulation products. In general, the amplitudes of the higher order products are small compared with the lower order. In a particular problem some consideration of where the principal products fall in the frequency band is required. The products just considered give a fair approximation for the problem of detection of a radio-frequency band of signal and noise followed by audio amplification. Certain other products should also be added to obtain higher accuracy. We have calculated the products of order zero and two; the next ones of importance are the fourth order, since the third-order products vanish in a perfectly linear rectifier. The fourth-order products in this case which fall in the audio band are of frequency $2p_0-p_r-p_s$, $p_0+p_q-p_r-p_s$, and $p_n+p_q-p_r-p_s$, where the subscripts n, q, r, s refer to the original noise component frequencies. The latter is, however, less important than the sixth-order product $3p_0-p_q-p_r-p_s$, which involves only three noise components. Expressions for the contributions from these products are given in Appendix III.

Figure 4 shows computed curves for the noise produced in an audio band by the various components. Curve A is $W_{sn}+W_{nn}$ and includes what are usually regarded as the principal contributors, the difference frequencies between signal and noise, and between individual noise components. Curve B is obtained by adding to

curve A, the contribution from the fourth-order products $2p_0-p_r-p_s$ and $p_0+p_q-p_r-p_s$ and the sixth-order products $3p_0-p_q-p_r-p_s$. Thus all products which include three or less noise fundamental components are included. The curves are plotted in terms of fraction of noise power received compared to the limiting noise when the mean signal input power is made indefinitely large compared to the mean input noise power. Some experimental points given by Williams[4] are shown for comparison. Williams gives the intercept at zero signal power as 35 percent; the theoretical value deduced here is $\pi/8$ or 39.27 percent. It will be noted that the inclusion of the higher order products improves the agreement between experimental and theoretical curves, even though the value of the intercept is unaffected by them. It should also be stressed that our analysis applies strictly to purely resistive networks. The conventional radio detector circuit (which was used by Williams), in which a condenser is shunted across a resistance in series with a diode, departs from the conditions here assumed because of the reactive element, the condenser. The customary approximation made in treating this circuit is that the condenser has infinite impedance in the audiofrequency range and zero impedance at the radiofrequencies. This leads to a bias on the detector which depends on the signal. The methods given here may be applied, but the resulting formulas are much more difficult from the standpoint of numerical computation.

A recent paper by Ragazzini[5] gives an approximate solution based on expanding the envelope of the input wave by the binomial theorem and retaining only the first two terms. The validity depends on the noise amplitude being small compared with the sum of signal and noise, and hence the result should agree with our solution in the neighborhood of $W_n/W_s=0$, which it does. When W_s/W_n is small, the error is appreciable. Ragazzini's result [Eq. (15) of the paper] expressed in our notation is

$$W_{sn}+W_{nn}\doteq\frac{\alpha^2}{\pi^2}\frac{W_n(1+\frac{1}{2}W_n/W_s)}{1+W_n/W_s}. \tag{49}$$

It will be seen by comparing the limiting values for $W_s/W_n=0$ with that of $W_s/W_n=\infty$ from (49) that the intercept of the curve of Fig. 4 would be 50 percent instead of our value of 39.27 percent.

The results given in the present paper have been compiled from unpublished memoranda and notes by the author extending back as far as 1935. Discussions with colleagues have been of great aid, and in particular acknowledgment is made to Messrs. S. O. Rice and R. Clark Jones for many helpful suggestions.

APPENDIX I

Evaluation of Integral for $\bar{I}$

Interchanging the order of integration in (9), we have

$$\bar{I}=\frac{\alpha}{\pi(2\pi W_n)^{\frac{1}{2}}}\int_0^{\pi}d\theta \times\int_0^{\infty}\exp\left[-(z-P_0\cos\theta)^2/2W_n\right]z\,dz. \tag{50}$$

By substituting $z=P_0\cos\theta+u(2W_n)^{\frac{1}{2}}$, we may evaluate the second integral in terms of the error function, obtaining

$$\begin{aligned}\bar{I}&=\frac{\alpha}{\pi^{\frac{1}{2}}}\int_0^{\pi}d\theta\int_{-P\cos\theta/(2W_n)^{\frac{1}{2}}}^{\infty}\exp(-u^2)\times\left[u(2W_n)^{\frac{1}{2}}+P_0\cos\theta\right]du\\&=\frac{\alpha}{\pi}\frac{(W_n)^{\frac{1}{2}}}{2\pi}\int_0^{\pi}\exp(-P_0^2\cos^2\theta/2W_n)d\theta\\&\quad+\frac{\alpha P_0}{2\pi}\int_0^{\pi}\operatorname{erf}\left[P_0\cos\theta/(2W_n)^{\frac{1}{2}}\right]\cos\theta\,d\theta\\&=\frac{\alpha}{\pi}\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\exp(-P_0^2/4W_n)\int_0^{\pi}\exp(-\cos2\theta/4W_n)d\theta\\&\quad+\frac{\alpha P_0}{2\pi}\int_0^{\pi}\frac{d}{d\theta}\left[\operatorname{erf}\left(\frac{P_0\cos\theta}{(2W_n)^{\frac{1}{2}}}\right)\sin\theta\right]d\theta\\&\quad-\frac{\alpha P_0}{2\pi}\int_0^{\pi}\sin\theta\frac{d}{d\theta}\left[\operatorname{erf}\frac{P_0\cos\theta}{(2W_n)^{\frac{1}{2}}}\right]d\theta\\&=\frac{\alpha}{2\pi}\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\exp(-W_s/2W_n)\\&\quad\times\int_0^{2\pi}\exp(-W_s\cos\Phi/2W_n)d\Phi\\&\quad+\frac{\alpha W_s}{2\pi(2\pi W_n)^{\frac{1}{2}}}\int_0^{2\pi}\exp(-W_s\cos\Phi/2W_n)\\&\quad\times(1-\cos\Phi)d\Phi\\&=\alpha\left(\frac{W_n}{2\pi}\right)^{\frac{1}{2}}\exp(-W_s/2W_n)\left\{I_0(W_s/2W_n)\right.\\&\quad\left.+\frac{W_s}{W_n}\left[I_0(W_s/2W_n)+I_1(W_s/2W_n)\right]\right\}.\end{aligned} \tag{10}$$

[4] F. C. Williams, J. Inst. Elec. Eng. **80**, 218–226 (1937).
[5] John R. Ragazzini, Proc. I. R. E. **30**, 277–288 (1942).

In the above we have made use of the relations:

$$\operatorname{erf} z=\frac{2}{(\pi)^{\frac{1}{2}}}\int_0^z \exp(-z^2)dz, \tag{51}$$

$$\frac{d}{dz}\operatorname{erf} z=\frac{2}{(\pi)^{\frac{1}{2}}}\exp(-z^2), \tag{52}$$

$$\int_0^{2\pi} e^{-z\cos\Phi}\cos m\Phi d\Phi=(-)^m 2\pi I_m(z). \tag{53}$$

APPENDIX II

Relations Between Hypergeometric and Bessel Functions

The modulation coefficients appearing in the linear rectification of noise are expressible in compact form in terms of the hypergeometric function:

$$\begin{aligned}{}_1F_1(a;c;-z)&=1-\frac{a}{c}\frac{z}{1!}+\frac{a(a+1)}{c(c+1)}\frac{z^2}{2!}-\cdots\\&=\frac{\Gamma(c)}{\Gamma(a)}\sum_{m=0}^{\infty}\frac{\Gamma(a+m)}{\Gamma(c+m)m!}(-z)^m.\end{aligned} \tag{54}$$

The ${}_1F_1$ function is a limiting case of the more familiar Gaussian hypergeometric function ${}_2F_1(a, b; c; z)$, *viz.*,

$${}_1F_1(a;c;z)=\operatorname*{Limit}_{b=\infty}{}_2F_1(a, b; c; z/b). \tag{55}$$

In certain special cases this function may be expressed in terms of exponential and Bessel functions. For example, by a formula given by Campbell and Foster,[6] we may show that

$${}_1F_1(\nu+\tfrac{1}{2};2\nu+1;-z)=\frac{2^{2\nu}\Gamma(\nu+1)e^{-z/2}}{(-z)^{\nu}}I_{\nu}(-z/2), \tag{56}$$

or setting $\nu=0$

$${}_1F_1(\tfrac{1}{2};1;-z)=e^{-z/2}I_0(z/2), \tag{57}$$

which is one of the functions appearing in our work.

We have also encountered the function ${}_1F_1(\frac{1}{2};2;-z)$ which is not directly reducible by the above formula. The reduction may be effected in a number of ways. By making use of the relation obtained from (56) by setting $\nu=1$,

$${}_1F_1(\tfrac{3}{2};3;-z)=\frac{4}{z}e^{-z/2}I_1(z/2) \tag{58}$$

and noting that

$$\begin{aligned}&{}_1F_1(\tfrac{1}{2};2;-z)-{}_1F_1(\tfrac{1}{2};1;-z)\\&=\frac{1}{\Gamma(1/2)}\sum_{m=0}^{\infty}\frac{\Gamma(m+1/2)}{m!(m+1)!}(-z)^m\\&\qquad-\frac{1}{\Gamma(1/2)}\sum_{m=0}^{\infty}\frac{\Gamma(m+1/2)}{(m!)^2}(-z)^m\\&=\frac{-1}{\Gamma(1/2)}\sum_{m=0}^{\infty}\frac{\Gamma(m+1/2)m}{m!(m+1)!}(-z)^m\\&=\frac{z}{\Gamma(1/2)}\sum_{m=0}^{\infty}\frac{\Gamma(m+3/2)}{(m+2)!m!}(-z)^m\\&=\frac{z}{4}{}_1F_1(\tfrac{3}{2};3;-z),\end{aligned} \tag{59}$$

we find that[7]

$${}_1F_1(\tfrac{1}{2};2;-z)=e^{-z/2}[I_0(z/2)+I_1(z/2)]. \tag{60}$$

It may also be verified by integrating the series directly that

$$\int_0^z {}_1F_1(\tfrac{1}{2};1;-z)dz=z\,{}_1F_1(\tfrac{1}{2};2;-z). \tag{61}$$

Combining this relation with (57) and (60) above, we deduce the indefinite integrals

$$\begin{aligned}&\int e^z I_0(x)dx=xe^z[I_0(x)-I_1(x)],\\&\int e^{-z}I_0(x)dx=xe^{-z}[I_0(x)+I_1(x)],\\&\int e^z I_1(x)dx=e^z[(1-x)I_0(x)+xI_1(x)],\\&\int e^{-z}I_1(x)dx=e^{-z}[(1+x)I_0(x)+xI_1(x)].\end{aligned} \tag{62}$$

These integrals may be derived by differentiating the right-hand members, and could, therefore, serve as a basis for an alternate derivation of (60).

In addition it was noted in Eq. (11) that the constant term in the modulation spectrum could be expressed in terms of ${}_1F_1(-\frac{1}{2};1;-z)$; from the equations given, it follows that we must have the relation:

$${}_1F_1(-\tfrac{1}{2};1;-z)=e^{-z/2}[(1+z)I_0(z/2)+zI_1(z/2)]. \tag{63}$$

Another interesting set of formulas which can be obtained as a by-product from (62) by setting $x=iy$ is:

$$\begin{aligned}&\int J_0(y)\cos y dy=y[J_0(y)\cos y+J_1(y)\sin y],\\&\int J_0(y)\sin y dy=y[J_0(y)\sin y-J_1(y)\cos y],\\&\int J_1(y)\cos y dy=yJ_1(y)\cos y-J_0(y)(y\sin y-\cos y),\\&\int J_1(y)\sin y dy=yJ_1(y)\sin y+J_0(y)(y\cos y-\sin y).\end{aligned} \tag{64}$$

The hypergeometric notation is particularly convenient in determining series expansions for the coefficients to be used for calculation when the variable z is either very small or very large. For small values of z, the form (54) suffices; for large values of z, we may use the general asymptotic expansion formula[8] for the real part of z positive:

$$\begin{aligned}{}_1F_1(a;c;-z)&=\frac{\Gamma(c)}{\Gamma(c-a)z^a}{}_2F_0(a, 1+a-c; 1/z)\\&=\frac{\Gamma(c)}{\Gamma(c-a)z^a}\left[1+\frac{a(1+a-c)}{1!z}\right.\\&\qquad\left.+\frac{a(a+1)(1+a-c)(2+a-c)}{2!z^2}+\cdots\right].\end{aligned} \tag{65}$$

[6] G. A. Campbell and R. M. Foster, "Fourier integrals for practical application," Bell System Monograph B-584, p. 32. See also reference 2, p. 191.

[7] The relation (60) was brought to the attention of the author by Mr. R. M. Foster.

[8] E. T. Copson, *Functions of a Complex Variable* (Oxford, 1935), pp. 264–265.

The series expansions required here could also be obtained from the appropriate series for Bessel functions. It will be noted, however, that the typical modulation coefficient can be expressed in terms of either a single ${}_1F_1$ function or several Bessel functions, so that manipulations must be performed on the series for the latter to give the final result. The Bessel functions, on the other hand, are more convenient for numerical computations because of the excellent tables available.

Reduction formulas for certain other hypergeometric functions are needed in evaluating the higher order products. They are:

$$ {}_1F_1(3/2;1;-z)=e^{-z/2}[(1-z)I_0(z/2)+I_1(z/2)], \tag{66}$$

$$ {}_1F_1(3/2;2;-z)=e^{-z/2}[I_0(z/2)-I_1(z/2)], \tag{67}$$

$$ {}_1F_1(5/2;4;-z)=\frac{4}{z}e^{-z/2}\left[\left(\frac{4}{z}+1\right)I_1(z/2)-I_0(z/2)\right]. \tag{68}$$

Derivation of these is facilitated by the use of the easily demonstrated relations:

$$ {}_1F_1(a;1;-z)=\frac{d}{dz}[z\,{}_1F_1(a;2;-z)], \tag{69}$$

$$ 2z\,{}_1F_1(a;2;-z)=\frac{d}{dz}[z^2\,{}_1F_1(a;3;-z)], \tag{70}$$

$$ {}_1F_1(3/2;3;-z)-{}_1F_1(3/2;2;-z)=\frac{z}{4}{}_1F_1(5/2;4;-z). \tag{71}$$

APPENDIX III

Higher Order Products

The methods described in Section II may be applied to calculate the general expression for the general modulation coefficient. The result is for the amplitude of the term $\cos mp_0t\cos p_{n1}t\cos p_{n2}t\cdots\cos p_{nM}t$:

$$ a_{mM}=\frac{(-)^{(m+M/2)+1}P_{n_1}P_{n_2}\cdots P_{n_M}\Gamma\left(\frac{m+M-1}{2}\right)\left(\frac{W_s}{W_n}\right)^{m/2}}{\pi(W_n/2)^{(M-1)/2}m!}\times{}_1F_1\left[\frac{m+M-1}{2};m+1;\frac{-W_s}{W_n}\right]. \tag{72}$$

The coefficient of the term $\cos(mp_0\pm p_{n1}\pm p_{n2}\pm\cdots p_{nM})t$ is a_{mM} divided by $2^{M-1}\epsilon_m$. The number of terms of a particular type falling in a particular frequency interval can be calculated by a method previously described by the author.[9] Under the assumed conditions that the original noise spectrum is either flat throughout a limited range, or falls off like an error function, and that the audio amplifier passes all the difference components in question, we find the following results:

$2p_0-p_r-p_s$:

$$ W_{2s,nn}=\frac{\alpha^2W_n}{8\pi}\exp(-W_s/W_n)I_1^2(W_s/2W_n); \tag{73}$$

$p_0+p_q-p_r-p_s$:

$$ W_{snnn}=\frac{\alpha^2W_s}{32\pi}\exp(-W_s/W_n)\times[I_0(W_s/2W_n)-I_1(W_s/2W_n)]^2; \tag{74}$$

$3p_0-p_q-p_r-p_s$:

$$ W_{3s,nnn}=\frac{\alpha^2W_s}{32\pi}\exp(-W_s/W_n)\times[(1+4W_n/W_s)I_1(W_s/2W_n)-I_0(W_s/2W_n)]^2. \tag{75}$$

This includes all beats containing not more than three noise fundamentals. The reductions of hypergeometric functions to exponential and Bessel functions given in Appendix II have been used in deriving the above results.

[9] W. R. Bennett, Bell Sys. Tech. J. **19**, 587–610 (1940).

A Keyboard Instrument in Just Intonation

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THE design for an organ in just intonation proposed in a previous article[1] has been set up and tested. A five-octave rank of eight-foot metal open diapason pipes of medium scale was duplicated from the stock of a local maker, who voiced the new set by comparison with our *C* pipes of speaking lengths four feet, two feet, one foot, and six inches. Both sets were mounted on windchests equipped with direct electric action. They were somewhat interspersed so that corresponding pipes from each set may be heard equally well. Tuning was equally tempered, the upper set based on *A*-440, the lower on *A*-436.3. No special methods were used, but more than ordinary care was taken since the whole effect turns on the reduction of errors. Twelve multiple-contact relays, one for each note of the chromatic scale, were wired to select pipes according to the setting of a twelve-position rotary cam switch. Three stop-knob switches were provided to permit the selection of just intonation or of either of the tempered scales which the instrument contains.

Thirty physics teachers witnessed a demonstration of this instrument in 1941. More than twenty were able to tell immediately whether a phrase was played in just intonation or in equal temperament. No preference vote was taken. A postwar demonstration is planned for a jury of musicians.

It has been shown[1] that the previous design minimizes the errors of the tempered scale in the major mode; but further difficulties arise in the minor mode.[2] Both the melodic and harmonic forms of the minor scale must be provided for. Two extra scale steps are accordingly presented in Tables Ia, Ib. Proceeding as before,[3] we see that now *three* tempered scales are needed, the first 15.65 cents higher, the second 0.95 cent higher, the third 13.65 cents lower. It is simpler to let one be 14.6 cents lower, another 29.3 cents lower, than the first; and this shows that we retain the previous design,[1] adding to it one more scale twice as far below. By providing three tempered scales we secure the additional advantage of a justly intoned fifth harmonic for mutation and mixture effects in conjunction with seven of the nine frequencies listed in Table Ia. By setting the two additional tempered scales below that containing *A*-440 we make it possible to tune wind instruments to an organ of this design. (They can be tuned down, but not up, because no provision is made for shortening their fundamental length.) The three proposed scales are shown in Tables IIa,

[1] C. Williamson, J. Acous. Soc. Am. **11**, 216 (1939).

[2] L. S. Lloyd, *Music and Sound* (Oxford University Press, London, 1937), p. 14; W. T. Bartholomew, *Acoustics of Music* (Prentice-Hall, New York, 1942), p. 177.

[3] See reference 1, footnote 8.

TABLE Ia. Scale of *A* minor. Frequencies in vibrations per second.

Note	*A*	*B*	*C*	*D*	*E*	*F*	*F♯*	*G*	*G♯*
Just	220.0	247.5	264.0	293.3	330.0	352.0	366.7	396.0	412.5
Tempered	220.0	246.9	261.6	293.7	329.6	349.2	370.0	392.0	415.3
Differences	0	+0.6	+2.4	−0.4	+0.4	+2.8	−3.3	+4.0	−2.8

TABLE Ib. Minor scale. Ratios in logarithmic cents.

Just	0	203.9	315.6	498.0	702.0	813.7	884.4	1017.6	1088.3
Tempered	0	200.0	300.0	500.0	700.0	800.0	900.0	1000.0	1100.0
Differences	0	+3.9	+15.6	−2.0	+2.0	+13.7	−15.6	+17.6	−11.7

TABLE IIa. Three proposed tempered scales. Frequencies in vibrations per second. Terms shown in boldface are chosen for the key of *A* minor.

220.0	233.1	246.9	**261.6**	277.2	293.7	311.1	329.6	**349.2**	370.0	**392.0**	415.3
218.2	231.1	**244.9**	259.4	274.9	**291.2**	308.5	**326.9**	346.3	366.9	388.7	411.8
216.3	**229.2**	242.8	257.2	**272.5**	288.7	**305.9**	324.1	343.4	**363.8**	385.5	**408.4**

TABLE IIb. Three proposed tempered scales. Ratios in logarithmic cents. Terms shown in boldface are chosen for minor key.

0.0	100.0	200.0	**300.0**	400.0	500.0	600.0	700.0	**800.0**	900.0	**1000.0**	1100.0
−14.6	85.4	**185.4**	285.4	385.4	**485.4**	585.4	**685.4**	785.4	885.4	985.4	1085.4
−29.3	**70.7**	170.7	270.7	**370.7**	470.7	**570.7**	670.7	770.7	**870.7**	970.7	**1070.7**

TABLE IIIa. Proposed approximation to the just scale of *A* minor. Frequencies in vibrations per second.

Note	*A*	*B*	*C*	*D*	*E*	*F*	*F*♯	*G*	*G*♯
Just scale	218.0	245.3	261.6	290.8	327.1	348.8	363.4	392.5	408.8
Approximation	218.2	244.9	261.6	291.2	326.9	349.2	363.8	392.0	408.4
Differences	−0.2	+0.4	0.0	−0.4	+0.2	−0.4	−0.4	+0.5	+0.4

TABLE IIIb. Proposed approximation to just minor scale. Ratios in logarithmic cents.

Just scale	−15.6	188.3	300.0	482.4	686.4	798.1	868.8	1002.0	1072.7
Approximation	−14.6	185.4	300.0	485.4	685.4	800.0	870.7	1000.0	1070.7
Differences	−1.0	+2.9	0.0	−3.0	+1.0	−1.9	−1.9	+2.0	+2.0

IIb; the results in Tables IIIa, IIIb. It will be noted that no error in Table IIIa is greater than 0.5 vibration per second. The accidentals furnished for use in the key of *A* minor are *A*♯, *C*♯, and *D*♯; corresponding choices are made in other keys. The complete scheme of selection is given in Table IV. Two switching mechanisms will be required, one for major keys, the other for minor. Table V shows the frequencies furnished in the keys of *C* major, *A* minor, and *A* major. Musicians will be interested in the enharmonic changes listed under *B*♭, *E*♭, and *A*♭. Similar changes are listed for other notes, but there is no way to indicate this fact in musical notation.

The added complexity, bulk, and cost of this design will vary with the nature of the keyboard instrument to which it is applied. These disadvantages may be insuperable for the pianoforte, and serious for the pipe-organ; but they are much less significant for electronic instruments or for the harmonium.

It is often said that the field for a practical keyboard instrument in just intonation is limited. In support, it is pointed out that much contemporary music is too chromatic to be suited to such an instrument. This is true; but more than nine-tenths of the musical compositions in existence are essentially diatonic in character; and these are used in still greater preponderance when music is performed, either publicly or privately. It is not our present purpose to consider whether any musicians do or should attempt to perform

TABLE IV. This table indicates how the terms are selected from Table IIa for use in any minor key; 1 from the upper row, 2 from the middle, 3 from the lower.

Key \ Note	*E*♭	*B*♭	*F*	*C*	*G*	*D*	*A*	*E*	*B*	*F*♯	*C*♯	*G*♯
E♭	2	2	2	3	3	3	3	3	1	1	1	2
B♭	2	2	2	2	3	3	3	3	3	1	1	1
F	1	2	2	2	2	3	3	3	3	3	1	1
C	1	1	2	2	2	2	3	3	3	3	3	1
G	1	1	1	2	2	2	2	3	3	3	3	3
D	3	1	1	1	2	2	2	2	3	3	3	3
A	3	3	1	1	1	2	2	2	2	3	3	3
E	3	3	3	1	1	1	2	2	2	2	3	3
B	3	3	3	3	1	1	1	2	2	2	2	3
F♯	3	3	3	3	3	1	1	1	2	2	2	2
C♯	2	3	3	3	3	3	1	1	1	2	2	2
G♯	2	2	3	3	3	3	3	1	1	1	2	2

TABLE V. Comparison of terms furnished in three related keys. Frequencies in vibrations per second.

Note	*A*	*B*♭	*B*	*C*	*C*♯	*D*	*E*♭	*E*	*F*	*F*♯	*G*	*A*♭
C major	216.3	231.1	242.8	259.4	272.5	291.2	308.5	324.1	346.3	363.8	388.7	411.8
A minor	218.2	229.2	244.9	261.6	272.5	291.2	305.9	326.9	349.2	363.8	392.0	408.4
A major	218.2	229.2	244.9	259.4	272.5	291.2	305.9	326.9	346.3	363.8	388.7	408.4
Note	*A*	*A*♯	*B*	*C*	*C*♯	*D*	*D*♯	*E*	*F*	*F*♯	*G*	*G*♯

in just intonation; this question has been discussed elsewhere.[4] What is here offered is a design for a conventional keyboard instrument that can be played in just intonation in any major or minor key, and instantly converted to tempered intonation when that is wanted.

The generous help of Robert Fischer, George Williamson, the late Professor Harry S. Hower, and the late Roy Lincoln, is gratefully acknowledged.

[4] C. Williamson, Am. J. Phys. **10**, 171 (1942).

THE JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA VOLUME 15, NUMBER 3 JANUARY, 1944

The Growing Appreciation of Music and Its Effect Upon the Choice of Music in Industry

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OBJECTIVE measurements, based on accumulated data, for the determination of the results of reduction of boredom and fatigue among industrial workers subjected to a bath of musical sound are liable to cover up individual reactions. A certain type of music which obviously satisfies some may annoy others. Some individuals have been conditioned to music as a background noise, others listen to it consciously. Whether such a conscious perception of music in industry is desirable or not, the fact remains that some people do listen consciously, even actively, i.e., with muscular response. Also, many individuals have strong preferences for certain kinds of music. On their own radio or phonograph they have the advantage of choice of musical literature and can turn off any undesirable program.

Since the avowed purpose of music in industry is to improve the morale of the workers, to create a pleasanter atmosphere in which to perform their tasks, and to reduce fatigue and boredom, it hardly seems sensible to risk the substitution of another type of boredom, resulting from "unwanted sound" as an antidote.

This is admittedly a sophisticated generation and its powers of discrimination have had marvelous opportunity to enhance the growing appreciation of the better things in life. Music, especially, has been well fostered through the radio broadcasting and the reproducing instruments. Accompanying comments have aided greatly in making the music understandable by the masses. In a short span of years Mr. and Mrs. Average Public have become intimately acquainted with an astoundingly large repertoire of good music. The term "good music" is not intended to cast aspersion on the more popular variety of musical offering, conceded to be of less lasting quality. The saving grace of much of the lighter type of music of today lies in the clever orchestrations designed to intrigue the jaded palate. Some of it, furthermore, is sufficiently reminiscent of the thematic material from which it was "borrowed" to induce a desire to know the original better. It must be confessed, unfortunately, that the converse is likewise true, namely, that the original has been forever ruined for many by the popular paraphrase, the "de-rangement." Some good is, on the whole, accomplished, however. This is but another example of what was meant by a satisfier or annoyer in music.

In considering the problems involved in the introduction of music in industry, one is prone to indulge in reminiscences. So many factors are involved, and even the much abused term "appreciation of music" is invested with a view and broader meaning when taking into account the intricate phenomenon of perception. The following observations are therefore intended merely as a stimulation of suggested procedure in analysis.

It is a matter of daily observation in the home that some members of the family work more efficiently to the accompaniment of the radio, whereas others must shut themselves away from the sound of the broadcast if they have serious work or studying to do. It is interesting to observe the person who plants himself close to the receiver while working out some complex problem in his school work, seemingly paying no attention to the radio program while concentrating on the work at hand. Yet he evidently takes in the music, too, and even the commentaries that go with it. In many instances the mistress of the house finds in the radio music a most satisfactory companion during an otherwise tiresome day of routine duties. The maid seems to thrive on this treatment, too. The choice of musical program is naturally an individual one.

The nice question of control of these factors in presenting music to large groups of workers in the industry is thus hardly one of simple solution. It would not be heresy to remark that some individuals do their work satisfactorily in spite of the music to which they are exposed rather than because of it. To others, of course, music offers a very definite excitation to increased activity

which cannot be denied. In fact, their habits demand it.

Sporadic attempts were made during World War I and thereafter to use music for the same purpose as is now considered advisable. Community singing and the like, now judged to be old-fashioned, seemed to offer promise. Each new generation pooh-poohs that which was thought desirable by its elders. Even though much of it was trivial, it is to be deplored that considerable of worth has been discarded with the unworthy stuff. The act of participation was desirable.

World War I definitely taught something about the effects of music on fatigue. When dead tired, the boys dragged themselves out of the trenches to be met along the line of march to the rear echelon by the band. The effect was electrifying. The staff officers frequently commented on the "esprit-de-corps" brought about by the music of the armed forces. Maestro Stokowski strongly voiced his opinion concerning the place of band music in the present world struggle. The musicians, however, do not seem to take kindly to his suggestion of sending them to the front line in armored tanks. Perhaps they have not acquired the taste for Molotov cocktails, or they may not approve of the acoustical qualities of the tanks.

The virtue of music is so generally assumed that an incident which occurred a short time ago came as a great surprise to a dear old master violinist of the old school. He accompanied a pupil of his on a visit to the hospital where her father was convalescing after a serious operation. The patient was starved for some music of the kind he had fondly encouraged in his daughter. The maestro took out his instrument and began to play, to the great delight of the convalescent. His joy was short-lived, however, for in stormed an irate nurse and ordered the playing stopped. Tears came to the patient's eyes. In wonderment the dear old teacher turned to the daughter and asked: "What is the matter? Doesn't she like music?" This possibility seemed as far from his comprehension as if the nurse didn't like flowers or babies. In explanation of her action it is obvious that while some of the patients may have desired the music, others were too ill to endure it.

Attention has been drawn lately to the attitude of the medical directors of the service men's convalescent hospitals toward the well-meaning but misguided efforts of communities to supply the patients with "home-made" music. Often such musical offerings must be declined. This may be "unwanted sound" when it is not known what kinds of music are specifically indicated for the sick. The professional musician has no delusions of grandeur concerning his product as a panacea for all ills, since he realizes that the therapeutic value of music is a variable over which he has as yet but little control. Its value is very difficult to measure objectively. Indeed there is some evidence in support of the fact that music has, at times, the power to lower the threshold value of pain. The famous surgeon Billroth was said to have become conscious of the pain of an abscessed tooth while listening to music. Previously he had been unaware that the tooth needed attention.

It has proved of great interest to attempt to apply some of the results already obtained from experimental psychology in the field of musical sound. This has always been limited, naturally, by the necessary simplifying assumptions which make it difficult to utilize the results in actual situations where they might well have real meaning. Reference is made primarily to the studies which have been made on the affective values of pitch, rhythm, time, and dynamics, and of the effects of the major and minor modes, of tone quality, and of the harmonic and melodic values of music. Obviously one must be reconciled to the fact that the net results of such attempted application can be no more valid than the assumptions made to aid in the desired solution. One rather interesting study was made by a group of graduate students under the writer's guidance. In this study, four different catagories of observers were used:

(1) those who liked music but admitted that they knew nothing about it,

(2) those who professed an absolute dislike for "the stuff" and would ordinarily go far out of their way to avoid it,

(3) those who were "crazy" about the latest song "hits" and dance band arrangements, and

(4) those who seemed to be intimately acquainted with the literature of the classical and more modern composers, but who had no formal musical training from a technical standpoint.

It is to be noted that none of these subjects was in the least interested in music as a profession, but all gave graciously of their time submitting to the study of psychogalvanic reflex, electrocardiogram, blood pressure, pulse, and breathing rate while listening to good phonographic reproductions of musical literature. With the wealth of recordings now available it was not difficult to avoid compositions with which any of the subjects might have been familiar. Thus the pleasure ordinarily derived from the recognition of old favorites was ruled out. Subjective responses obtained upon request for a description dependent upon mental imagery were extremely vague and even caused embarrassment. Subconscious response to the music can be summed up briefly. As measured by the battery of instruments used in this experiment, the findings indicated that it seemed to be a matter of degree of response rather than a type of response to the musical stimulus. That is to say, the range of fluctuation was more generally a function of relative intensity, dissonance, and dynamic accentuation than of the type of composition. Yet, on the other hand, it must not be inferred that the type of composition played had no part in the end results, for it was obvious that some kinds of music produced all but nauseating symptoms in some of the observers. Thus, although the observers' comments, when invited, dealt variously with factors involving rhythm, tempo, dynamics, tone quality, and the harmonic and melodic considerations, the psychological reflexes and other data obtained by psychometric methods apparently failed to bear out their introspections. On the other hand, when guided by adroit but sympathetic questions, these same subjects meaningfully expressed their attitudes toward the music heard. Such expressions, in terms of what the music meant to them, were naturally even more intensely voiced when the subjects listened to music with which they were more familiar. The individual differences in response to harmonic *versus* dynamic gradations, as well as timbre effects, pitch, and rhythm variation, were most interesting and well deserve further investigation.

While working in the field of pitch as a function of the rate and extent of frequency modulation, the writer became aware of an interesting muscular reaction on the part of the naive listener who was being subjected to stimuli of short pulses of sound at approximately the threshold value of 25 milliseconds. This observation was quite apart from the main issue involved in the experiment, but definitely encouraged a bit of further probing. It should be explained that the observers were subjected to two main categories of pure tonal stimuli, gliding over various musical intervals during brief periods of time. The subjects were called upon to attempt a possible recognition of the extent of the musical intervals by a matching technique. These two types of glides might be called:

(1) linear, in which the frequency changed in direction consistently as a function of time, and

(2) sinusoidal, in which the frequency changed more gradually at the beginning and end of the glide, and reached a maximum rate of movement in the mid-portion of the interval.

The intriguing observation, not anticipated in the experimental problem, was that the subjects tended to hear the two types of glide in a somewhat different manner. The sinusoidal glide had what the subjects described as a "whip-like" character, whereas the linear glide appealed to them as a "thrust" or "bump." The meaning of this difference is not entirely clear, but it was so general a response that the phenomenon invited further consideration. It would be well to consider a possible interpretation of the adjectival quality of the linear and sinusoidal types of frequency modulation in short pulses of sound. The reaction was so strongly experienced by the sensitive observers, motivated by a sort of musical challenge to a fine degree of concentration, that in describing the sensation of the frequency modulation they quite universally utilized a hand movement while seeking for an adequate realization of the stimulus in terms of an up or down pitch movement. Further discussion and introspective analysis gave evidence of a strong association with the subjects' reactions to a state of tension very definitely correlated with the rate, extent, and type of frequency modulation. An attempt was therefore made to justify the resulting psychological effect on the basis of an objectively measurable physical state, in which the tension was shown to be roughly

proportional to the intensity of the stimulus, although differing greatly in individuals. Now, although the above phenomenon is in no way dependent on an appreciation of music and would probably be difficult to measure directly while the subject was normally at work at his daily routine, it appears to be a recognizable reaction of the organism's muscular system while subjected to at least one of music's many interesting factors.

Another interesting experiment was tried with a group of advanced students in the graphic arts. They were requested to draw and paint in the abstract while listening to unfamiliar music of various types. They were instructed to avoid representation of mental imagery of the kaleidoscopic changes involved in the music. This obviously implied something more sophisticated than the kindergarten-like response in keeping time with the music. Compositions of considerable length, furthermore, discouraged mere delineation of the melodic and rhythmic characterization. The graphical improvizations made no pretense of following the minor changes of mood, but were drawn or painted in broad sweeping strokes in response to more general characterization. The end results, after some practice in such abstractions, gave evidence of a truly uncanny similarity of design and general atmosphere on the part of the artists in response to the same compositions. It was indeed surprising, because they had no possible notion of the programmatic attitude of the composers.

This surprising carry-over from one field of art to another definitely evidenced an appreciation of music which showed itself in vivid motor responses writing their own signatures on the artist's self-expression. Surely the artisan in the industry can be depended upon to evidence motor responses of a similar nature, quite unconsciously, when he is exposed to music. It doesn't seem essential that the subject become acquainted with the meaning of music. The bodily reactions and specific muscular responses of the sophisticated listener may or may not be different from the reactions of persons to whom music is nothing but a chaotic melange of sounds. It is extremely difficult to decide what can be objectively, but meaningfully, measured. Although your pet dog wags its tail in evident pleasure, one does not expect to cause any particular happiness in the animal by deliberately wiggling its tail. Although music seems to be generally accepted as a desirable thing, the specific effects must be considered in terms of its application.

Not so long ago, music with one's meals was considered a very desirable aid to digestion. This novel idea was so generally accepted that it became possible to overlook even the poor quality of the food, at times, for the sake of the musical excitation. However, a growing appreciation of music set higher standards for even this type of music, with the result that every cosmopolitan center had in it some enterprising restaurants which boldly advertised "No Orchestral Din!" Considering this same ever-growing appreciation of music, industry cannot afford to gamble with the possibility of a similar reaction.

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Some Experiments on an Elephant Bell

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(Received June 21, 1943)

INTRODUCTORY

SOMETIME ago this writer had occasion to perform some experiments on a small bell. The sound characteristics were so unusual that a rather complete analysis was made.

The sample is illustrated in the photograph of Fig. 1. These bells, made in India, are referred to by dealers as "elephant bells," and come in a variety of sizes, of the same general design. They are sold by curio shops specializing in Oriental novelties for household use, such as dinner gongs and the like. The bell is formed of a single cored casting. The metal appears to be ordinary yellow brass. The general form is roughly that of an ellipsoid, the upper half consisting of a hollow shell, the lower half, a series of 15 inwardly curving prongs. The sound bow is formed by a ring of triangular cross section around the outer surface. An integrally cast knob projecting from the top serves as a handle. The shell is not uniform in thickness nor are the prongs identical.

GENERAL THEORY OF BELLS

Bell vibrations have been studied by prominent physicists in considerable detail. Lord Rayleigh gives an excellent fundamental analysis of bells in his *Theory of Sound* first published in 1877. A brief review of the elementary theory will be given which may be skipped by readers already familiar with the subject.

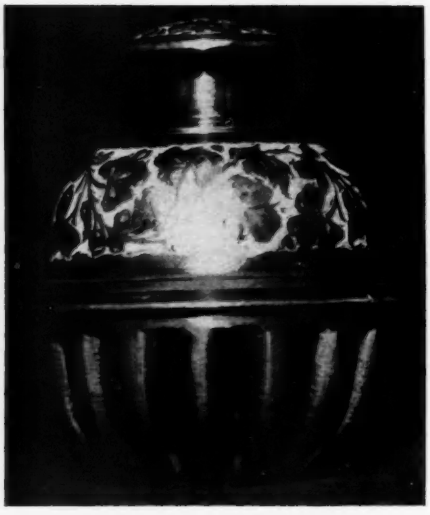

FIG. 1.

When a bell-shaped body is excited by striking, that point at which the blow is applied is displaced from its position of rest by the transient force. Upon removal of the force, the elasticity of the shell causes it to return towards its normal shape. The inertia or mass, however, carries the displaced point beyond its original position and the lip of the bell vibrates inward and outward at a frequency depending upon the relation between the mass and stiffness forming the vibrating system. The lowest or fundamental mode of vibration is elliptical with four nodal meridians as will be understood by referring to the diagram of Fig. 2. This is the simplest mode of vibration for any bell. It will be seen that where these nodal meridians intersect the rim, there is no motion of the shell normal to the bell axis but at points midway between these meridians the normal motion is at a maximum. At any given instant or phase in the vibration, the two points of maximum normal motion diametrically opposite each other are moving in opposite directions. The nodal points, however, are not positions of rest. Here the rim of the bell moves tangent to its circumference. Rayleigh showed that this tangential motion is half the maximum normal motion for the fundamental mode of vibration. If the weight of the shell is not uniform—that is, if some points have a small additional load—a slight augmentation of period occurs which will differ according to whether the heavier point coincides with a node of the normal or of the tangential motion; the augmentation is greater in the latter case than in the former. The sound produced will therefore depend on the place of excitation; in general both tones will be heard which interfere and generate beats, the frequency of which is equal to the difference between the frequencies of the two tones.

The pitch or frequency of the vibration is determined by the same general laws that govern any vibrating system. For example, if we suspend a weight on the end of a spring and set the weight into vibration by pulling and releasing it, we know that the frequency, or number of vibrations per second, is a function of the mass of the weight and the elasticity or stiffness of the spring. The weaker the spring, the lower the vibration frequency for a given weight; and the heavier the weight, the lower the frequency for a spring of given stiffness. Similarly, for a bell of given shell thickness, adding weight at the rim or sound bow will lower the vibration frequency.

A bell can and invariably does vibrate simultaneously in other and more complicated modes than the one described. In general, the vibrations will not be of the same intensity for all modes. Some will be stronger, others weaker. Likewise the rate of decay of each frequency will differ. Some of the tones will be very strong immediately after impact but will decay quite rapidly; others may be less prominent at the start but will decay so very gradually as ultimately to remain in complete possession of the field. The fundamental mode of vibration which is sometimes called the "hum note" may be recognized by its persistence beyond all other tones produced. It will be apparent that we cannot assign a definite rate of decay for the sound of a bell because scarcely any two of the component vibrations decay at the same rate. It will likewise be clear that any attempt at quantitative analysis of a bell tone must necessarily be qualified by the conditions under which the tone was produced and most particularly the time following excitation at which the analysis was made.

In addition to the mechanical vibration characteristics discussed, we have certain acoustical influences that must be considered. First, when two or more tones are sounded simultaneously, interference of the sound waves develops additional frequencies that are given by the sum and difference of the component tones. Thus a sound analysis would be expected to show more frequencies than the vibration analysis due to the presence of these combination tones. A second influence relates to the resonance of the air cavity within the shell. Any vibration component having a frequency which corresponds or is close to this cavity resonance will excite the latter into vibration at its own resonant frequency. Finally, it is necessary to consider the size of the bell with respect to the lowest frequency it can efficiently radiate. It is well known that a vibrating body cannot efficiently radiate a sound whose wavelength is greater than twice the diameter of the vibrating surface. Thus while it is possible to design bells of small size having low fundamental vibration frequencies it does not follow that the radiated sound will have the same timbre as that from a larger bell vibrating at the same frequencies.

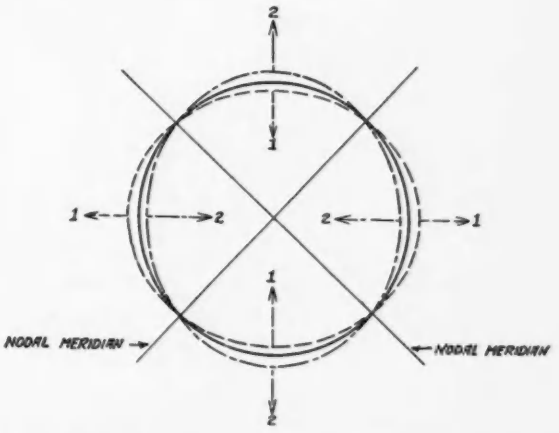

FIG. 2. Bell in elliptical vibration. Solid circle shows rim of bell at rest. Dotted lines show maximum deformation; points *1* and *2* represent opposite phases of cycle.

QUALIFYING CONDITIONS

The objective of these experiments was to analyze the sound sensation imparted by the bell to the ear. In a bell sound of percussion origin the frequency characteristics pass through an infinite number of changes as the sound dies out, due to the difference in decay rates of the individual components. If we take the analysis immediately following the strike the high frequencies will in general be more prominent; if after a very long interval, only the more persistent modes of vibration will remain and the resultant tone will be very different. In the data for the sound and vibration spectra the relative intensities shown represent the maximum ballistic throw of the meter; thus the analysis is for a time interval of the order of 0.25 second following the strike.

SOUND ANALYSIS

Preparation of Sample

This bell is normally struck by a small rounded brass clapper suspended from a wire link attached inside the top of the shell. Since it was essential to supply some more uniform means of excitation than could be accomplished by shaking the bell, a special striking mechanism was prepared from the motor of a vibrating electric bell. A brass hammer with a rounded striking face and of the same mass as the original clapper was attached to the end of a flexible arm in turn secured to the armature of the bell motor. The bell itself was secured in a yoke of soft wood and the striking mechanism clamped to a bracket so that the hammer projected up inside, and impacted against the bell opposite the sound bow. The bell was rotated and positioned until the clearest and most consistent tone was produced by successive impacts of the striker and cemented in this position to prevent shifting. The striking mechanism was damped with viscous material to eliminate spurious vibrations. The magnetostriction "thump" normally developed when the striker circuit was broken was eliminated by a shunt condenser of suitable capacitance across the windings. The striker was controlled by an electronic impulse relay and succeeding impacts were spaced sufficiently to attain a uniform excitation within 1 or 2 db between successive strikes. The entire assembly was suspended on sponge rubber within a heavily sound-insulated and damped cabinet and a microphone placed six inches from the bell at a position normal to the axis and in the same plane as the sound bow.

The microphone was connected to a sound level meter and the output of this meter connected to a sound analyzer which was manually swept through the frequency range.

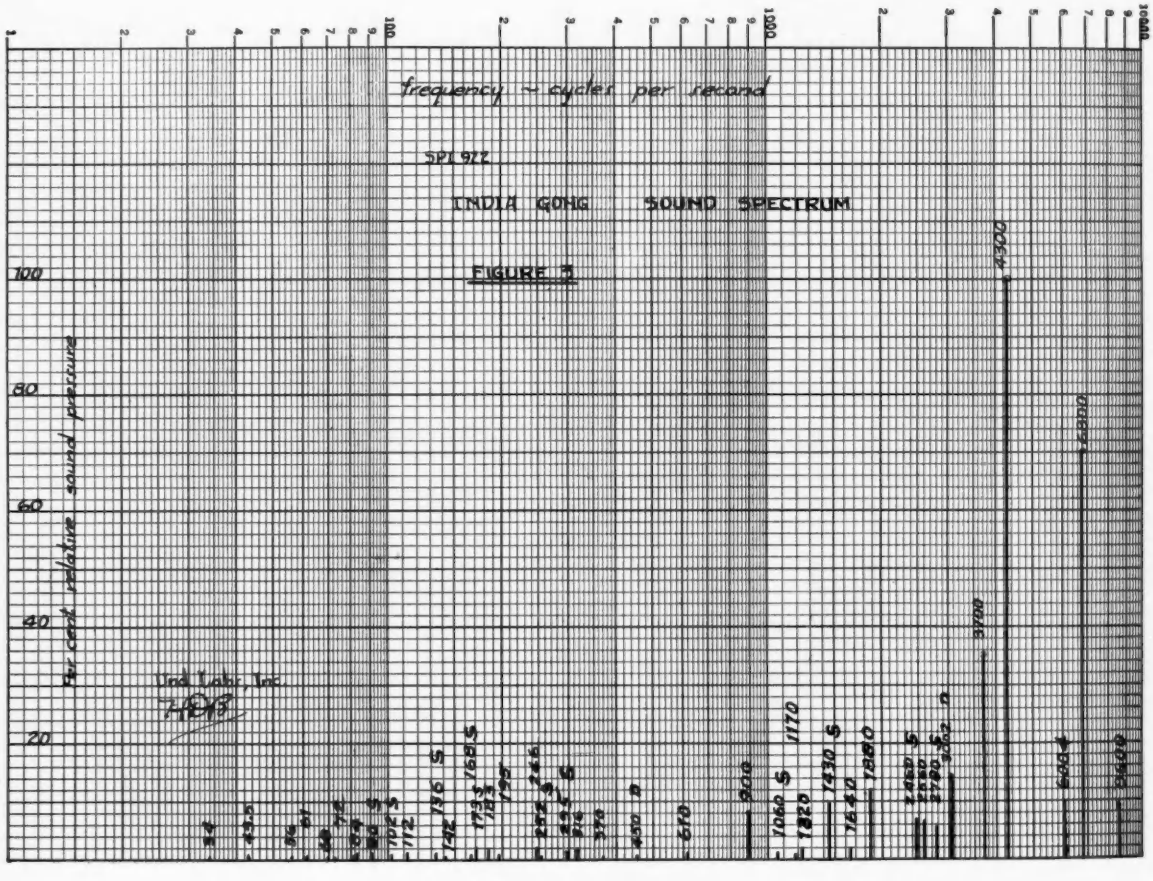

FIG. 3. India gong sound spectrum.

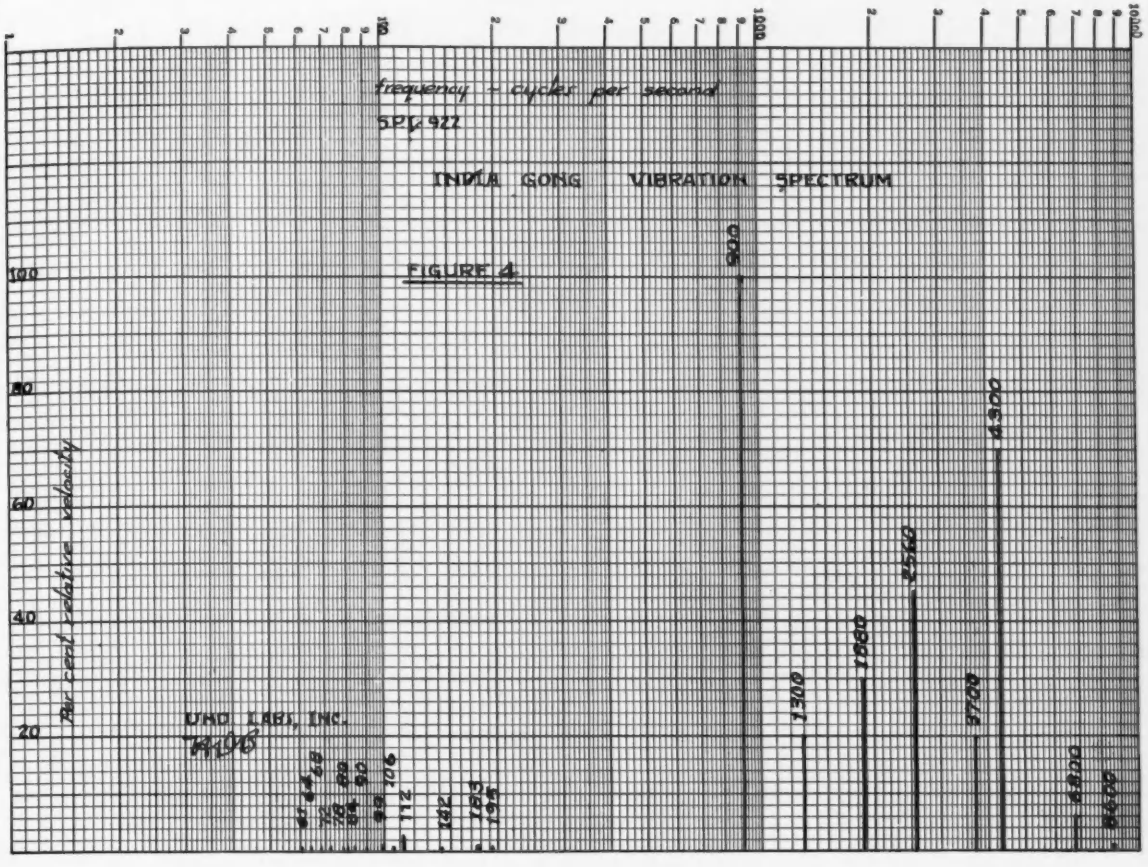

FIG. 4. India gong vibration spectrum.

Results of the sound analysis are given in sound spectrum of Fig. 3. A large number of components in the low frequency range were recorded, which may seem surprising in a bell of this size; but they were found, as expected, to be due to the vibration of the prongs. These prongs vibrate as cantilevers. These low frequencies contribute little to the total intensity of the sound but do materially influence the timbre or tone quality. A number of the frequencies were readily identified as combination tones, that is, sum and difference of two fundamental components. These are marked *S* and *D*, respectively, on the chart.

VIBRATION ANALYSIS

A light weight vibration translating device of a type used for the reproduction of vertical radio transcriptions was employed to pick up the vibration from the sound bow of the bell. The stylus of the pick-up was placed in contact with the rim of the bell, a tiny prick punch mark having been made to retain the stylus, and was held in contact at a pressure of 22 grams. The total moving mass of the pick-up was of the order of 50 milligrams which was sufficiently slight so as not to affect the vibrations of the sample. The output of the vibration pick-up was connected to the sound level meter and the remainder of the operating technique corresponded to that described for the sound analysis.

The vibration spectrum is given in Fig. 4. The strongest component was found to be 900 cycles. A group of low frequencies below 200 cycles again shows the individual vibrations of the prongs. A fairly strong vibration component at 1300 cycles per second could not be matched in the sound spectrum, the nearest component having a fre-

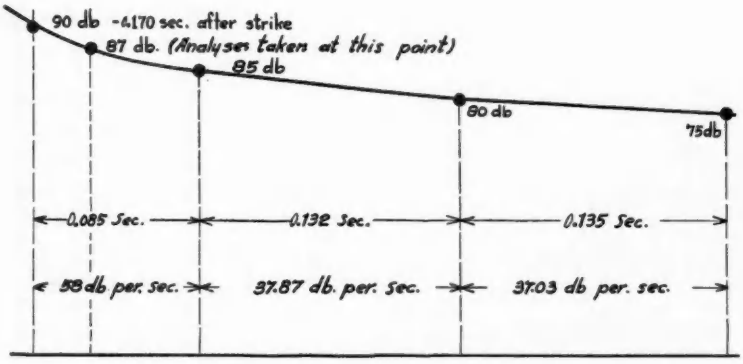

FIG. 5. Rate of decay—total sound. Maximum intensity—39 db.

quency of 1320 cycles. This discrepancy is probably due to the fact that the vibration analysis was carried out from a single point on the shell.

MEASUREMENT OF DECAY RATE OF TOTAL SOUND

The general set-up and apparatus were as described for the sound analysis, excepting that the output of the sound level meter was connected to the deflection terminals of a cathode-ray oscillograph. A camera of the shutterless moving film type was used to photograph the pattern at a suitable film speed. The impulse relay was set to strike the bell at two-second intervals and a film record was made in conventional fashion. An amplitude calibration was placed on the film by a series of still exposures in which a steady voltage passed through the sound level meter and caused it to deflect the cathode beam successively in steps of 1 and 5 decibels as read from the meter. These calibration marks were superimposed on the film in printing so that the sound level in decibels could be determined at any position along the decay curve.

Figure 5 is a calibration drawing taken from an enlargement of the original film. The maximum sound intensity given by the oscillographic record was 93 db and occurred approximately 15 milliseconds following the strike. The maximum

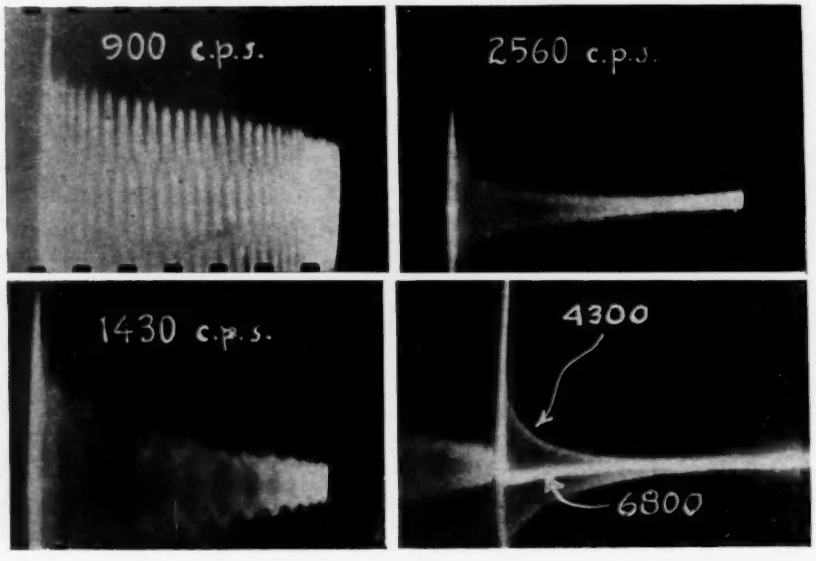

FIG. 6. Five-second sweep.

sound level meter reading of 87 db which is the value at which all the data were taken occurred approximately 0.24 second following impact and is in agreement with the specified ballistic characteristics of the instrument. The rate of decay starting from a value of 90 db was 0.085 second for the first 5-db drop, or 58 db per second. The next 5-db decline required 0.132 second, equivalent to 37.87 db per second. The following 5-db drop required 0.135 second equivalent to 37.03 db per second.

INVESTIGATION OF INDIVIDUAL RATES OF DECAY FOR SOME OF THE MORE PROMINENT FREQUENCIES

For this experiment the general set-up was similar to the previous one excepting that still rather than moving film technique was employed to secure the oscillographic records. The sound level meter was connected to the wave analyzer and the latter successively set on each of the frequencies measured so that the pattern for each exposure was for a single frequency, others being filtered out. In this way a graphic comparison was obtained between the decay rates of the different frequencies measured. Two different sweep rates were used, one of five seconds for the frequencies having the slowest decay and a one-second sweep for those having a more rapid rate of decay.

The results are shown in oscillograms of Figs. 6 to 8. The 900-cycle component was the most persistent by a substantial margin and strong beats occurring at the rate of approximately 8 per second are clearly visible. These beats are due to irregularity in the mass distribution of the bell as discussed in the opening section of this report. Similar beats are also prominently indicated in other components. The rate of decay in decibels per second for the three most persistent tones was measured and the order of decay rates for the ten most prominent components is tabulated (Table I).

LOCATION OF CAVITY RESONANCE COMPONENT

The air cavity within the shell is subject to acoustic resonance and will propagate this frequency if excited by one or more of the vibration components. It has been determined that the sound field radiated by a bell is strongest in the plane of the sound bow and weakest at a point along the bell axis. In fact, the mouth of the bell which would seem to correspond to the horn of a loudspeaker is almost a dead spot insofar as the sound radiated by mechanical vibration of the shell is concerned. On the other hand, it is evident that sound projected by the vibrating air cavity should be strongest in line with the mouth and weaker in the sound-bow plane. The theoretical cavity resonance of the air space was calculated

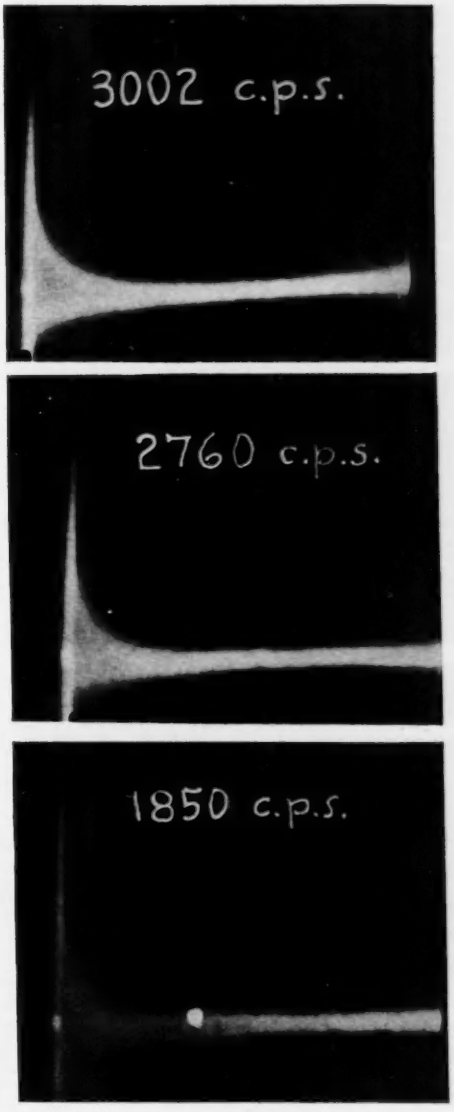

FIG. 7. Five-second sweep.

and the frequency in the sound spectrum corresponding most closely to the results was investigated by orienting the microphone about the bell to determine whether the radiation pattern corresponded to the air cavity or mechanical vibration of the shell.

The theoretical value for the cavity resonance was found to be approximately 3000 cycles per second. Examination of the sound spectrum disclosed a fairly strong component at 3002 cycles per second with no corresponding component in the vibration spectrum. The wave analyzer was tuned to this frequency and the microphone rotated about the bell in a plane parallel to the axis. The sound intensity for this frequency was at a minimum at a point opposite the sound bow and at a maximum on the bell axis in line with the mouth indicating that this frequency was due to the acoustic resonance of the air cavity. Since no vibration component was found at or near this frequency, it was of interest to determine the manner of excitation. Reference to the vibration spectrum discloses that the frequencies of 1300 and 4300 cycles, both prominent in this spectrum, yield a difference frequency of 3000 cycles per second. This is sufficiently close to the cavity resonance to excite the latter into vibration in the manner described and apparently is the source of the tone.

DETERMINATION OF THE STRIKE NOTE

The strike note of a bell is the sensation of pitch received when several bells are struck in succession as in a carillon or chime. The pitch of church bells as given by the makers refers to this strike note. The exact manner in which the strike note is produced apparently remains a mystery. Some investigators have reported bells in which no component tone corresponding to the strike note could be found. In many cases the strike note was found to be an octave below the nearest corresponding frequency in the spectrum of the bell. It has been suggested that the pitch or strike note of a bell is probably in part a function of the characteristics of the human ear itself. For this experiment the bell was struck at a frequency of about one blow every 2 seconds and was completely enclosed within the acoustic chamber so that the direct sound was not audible to the observer. The microphone was connected to an audio-frequency amplifier of high quality and the sound of the bell was reproduced in a loudspeaker. An audio-frequency oscillator was connected into another input channel of the same amplifier and keyed so that a pure sine frequency from the amplifier could be caused to issue from the loudspeaker alternately with the sound of the bell. The oscillator was then adjusted until the pure frequency most nearly matched, in the

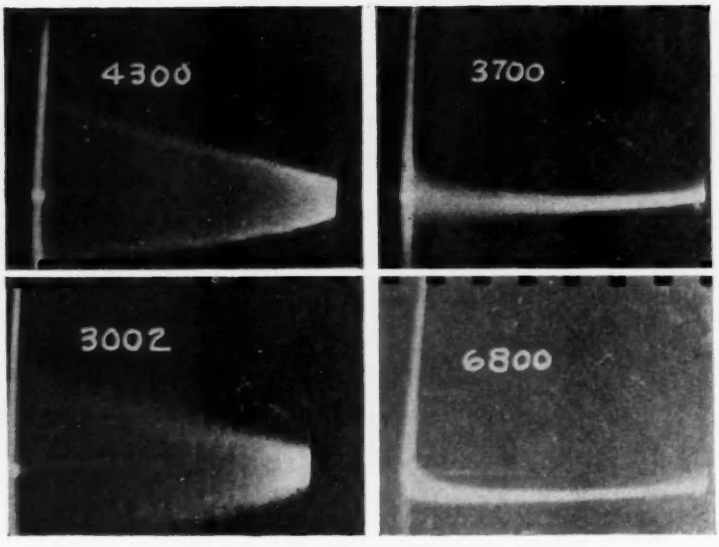

FIG. 8. One-second sweep.

TABLE I. Order of decay rates.

Frequency in cycles per second	Decay rates in decibels per second
900	1.25
1430	3.12
2560	4.17
4300	
3002	
1850	
2760	
3700	
6800	
8600	

opinion of the observer, the general pitch or tone of the bell. Non-linear distortion introduced by the ear was avoided by adjusting both sounds to equal intensity.

This test was repeated several times and on different days to eliminate as nearly as possible variances in the human element. The oscillator frequency that most nearly corresponded in the opinion of the observers to the general pitch of the bell was 370 cycles per second.

CONCLUSIONS

It is apparent that the designer of this bell sought to achieve a low and mellow tone quality in a small-sized unit. The prongs extending downward from the sound bow have the physical effect of greatly increasing the effective mass at the rim of the bell without also increasing the stiffness of the shell. A substantial lowering in the vibration periods of the shell is thereby achieved. The diameter of the bell ($6\frac{1}{2}$ centimeters) would place the sound radiation cut-off at a frequency of approximately 2700 cycles per second. Thus from the standpoint of acoustic efficiency the design is a poor one. On the other hand, the bell very definitely gives the auditory impression of a much lower pitch than the actual component frequencies would appear capable of producing. The strike note or impression of pitch received by an observer was found to be 370 cycles per second. No such component occurred in the vibration spectrum. A feeble component appeared in the sound spectrum at this frequency but not enough to account for the strike note. It is well known that if a harmonic series is sounded from which the fundamental is omitted, the ear automatically tends to supply the missing tone. The sound spectrum of this bell, however, does not show an ascending harmonic series from a 370-cycle fundamental although we do find a very strong component at 3700 cycles per second which would be the tenth. It is not entirely clear to this writer how the sound spectrum of this bell could give such a definite strike note of 370 cycles per second.

Most of the important components were accompanied by strong beats due to the irregular mass distribution of the shell. These beats are responsible for the wavering quality of the general tone giving the impression that the total sound is more complex in character than the actual analysis disclosed. In any event, it is evident that the actual sensation of pitch produced by this bell is an auditory illusion which, considering the country of the sample's origin, is not entirely inappropriate.

Acoustical Society News

Notice to Acoustical Society Members in the Armed Services

Acoustical Society members in the armed services may, at their request, have their membership suspended for the duration. Suspended members are not required to pay dues, but they remain on the membership list and receive programs, announcements, etc., but not the Journal. Any member in the armed services who finds himself too occupied to read the Journal may have his membership suspended by writing to Secretary Wallace Waterfall, 120 South LaSalle Street, Chicago, Illinois.

Meeting

The next meeting of the Acoustical Society of America will be held on May 12 and 13, 1944, at the Hotel Pennsylvania in New York City. In addition to the usual program of contributed papers, arrangements are being made for a group of related papers on "the use of sound waves for the study of solids and liquids" together with symposia on the subjects of "prevention and correction of hearing impairment" and "musical acoustics." Any members or friends of the society wishing to present papers at this meeting are invited to send their suggestions to Robert S. Shankland, Chairman of the Program Committee, 50th floor, 350 Fifth Avenue, New York City.

New Members

William Alexander Allen
4 Briar Road
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England
Architect
Building Research Station

Jack Wayne Ballou
Underwater Sound Laboratory
Harvard University
Cambridge, Massachusetts
Physicist

Harry Owen Boord, Jr.
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Analysis & Control Supervisor
Owens-Corning Fiberglas Corporation

Harvey Brooks
Underwater Sound Laboratory
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Central Institute for the Deaf

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Amplifier Company of America

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Research Engineer, Columbia University

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Cambridge, Massachusetts

Eric Arthur Walker
23 Morton Street, Arlington, Massachusetts
Assistant Director, Underwater Sound Laboratory
Harvard University
Cambridge, Massachusetts

Philip Yaffee
317 Third Street, S.E., Apt. 26
Washington 3, D. C.
Electrical Engineer
Naval Ordnance Laboratory
Navy Yard
Washington, D. C.

Fellows	162
Members	746
Total membership	908

Current Publications on Acoustics

F. A. FIRESTONE
147 Randall Laboratory, University of Michigan, Ann Arbor, Michigan

Book Review

Dynamical Analogies. HARRY F. OLSON. Pp. 196+xi, Figs. 59, $5\frac{3}{4}''\times 8\frac{3}{4}''$. D. Van Nostrand Company, Inc., New York, 1943. Price $2.75.

The object of this book is to make the reader familiar with a system of analogies between acoustical systems, mechanical rectilinear and rotational systems, and the electrical systems studied by the electrical and telephone engineer. By using such analogies the more familiar solutions and methods of the electrical science can be immediately applied to similar problems existing for mechanical and acoustical structures. Using the system of analogies first pointed out by Maxwell, the book develops the similarities between mass, moment of inertia, acoustical inertance, and electrical inductance; mechanical compliance, acoustical capacitance, moment of compliance, and electrical capacitance; and mechanical rectilinear or rotational resistance, and acoustical resistance with electrical resistance. By joining such units together through idealized elements, such as weightless and infinitely stiff levers, and infinitely stiff gear systems whose moments of inertia can be neglected, the writer shows that any of the complicated electrical networks, such as wave filters, and attenuation and phase equalizers, can be reproduced in mechanical or acoustical form. The book starts with simple single-mesh networks and progresses by easy steps to the more complicated filter and correcting networks. An interesting chapter is devoted to the transient response of mechanical and acoustical systems. Two chapters are devoted to the interaction between electrical and mechanical or acoustical systems. One chapter considers the transfer of electrical to mechanical energy and the other the transfer of mechanical to electrical energy. The modes of transformation studied are the electrodynamic, the electromagnetic, the electrostatic, the magnetostriction, and the piezoelectric converting systems. There is one chapter devoted to general theorems and a final chapter devoted to a few of the mechanical and acoustical devices that have been developed as a consequence of their similarity to electrical systems.

The analogies presented are the analogies between "lumped constant" systems and no account is given of the analogies and relations between "distributed constant" systems. This represents a rather serious limitation of the types of mechanical systems that can be portrayed, for it is considerably more difficult to obtain a mechanical or acoustical system that can be considered lumped than is the case for an electrical system. No consideration is given in the book to the question of how actual elements, such as levers and gear systems differ from the ideal weightless and infinitely stiff levers and gear systems, and what modifications have to be introduced to make the ideal correspond to the actual.

The book uses entirely the Maxwell system of analogies which identifies electrical force with mechanical force or acoustic pressure, and electrical current with linear mechanical velocity or acoustic volume velocity. This procedure has the merit of requiring the reader to learn only the most widely accepted set of analogies. However, this is not the only set of analogies possible since the differential equations that are the basis for the analogy can be written in several forms. The form proposed by Firestone in which electrical force is identified with mechanical velocity or acoustical volume velocity, and electrical current with mechanical force or acoustic pressure has many merits. This is particularly true when a coupling of mechanical and electrical systems occurs through an electromagnetic or magnetostrictive driving system. For example, if this analogy were used the two separate mechanical and electrical circuits of Fig. 9.1 could be joined into one electromechanical circuit.

As a presentation of "lumped constant" mechanical and electrical analogies, the book is the most complete treatment known to the reviewer. In no other book is it possible to find all the combinations of series and shunt masses and compliances shown here. The illustrations are self-contained, and the analogies and the performance curves for the type of circuit are readily seen. The electrical, mechanical, or communication engineer who works with mechanical or electromechanical systems should have it for his library. Sooner or later he will find a problem for which he will obtain assistance from the wide variety of examples shown in this volume.

W. P. MASON
Bell Telephone Laboratories
New York, New York

References to Contemporary Papers on Acoustics

MOST of the titles of papers appearing in other languages than English have been translated. Abstracts in English of many foreign papers have appeared or soon will appear in Science Abstracts, Section A. Where references are made to Science Abstracts, the reference is to the volume number and abstract number. The abbreviations of the names of journals are those used in Science Abstracts and can be found in any annual index to those abstracts.

The numbers appearing at the head of each entry are the numbers which identify the subject headings in the Cumulative Index of this Journal issued in November, 1939. The same Classification of Subjects can be found in the index to Volume 14.

Compiled with the generous assistance of Samuel Sass, Physics Librarian, University of Michigan.

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2. Architectural Acoustics

2.2 **The Acoustics of Broadcasting Studios.** W. Furrer. Bull. de l'Assoc. Suisse des Elec. **33,** 305–310 (June 3, 1942).

2.4 **Acoustic Room and Test Apparatus.** Bell Lab. Rec. **22,** No. 1, 15 (Sept. 1943).

2.7 **Reverberation in Small Glass Tubes.** S. M. Cox. Nature **152,** 357–358 (Sept. 25, 1943).

2.8 **An Apparatus for the Investigation of Echo Phenomena in Closed Spaces.** B. Burger. Hochfrequenztechn. u. Elektroakustik **61,** 75–82 (March, 1943); Wireless Engineer **20,** 2743A (1943).

2.9 **Haydite Units Supply Sound Insulation in NBC Building.** Concrete **51,** 21 (July, 1943).

2.9 **Sound Insulation.** W. Allen. J. Roy. Soc. Arts **91,** 135–147 (Feb. 5, 1943). Sci. Abs. **A46,** 1389 (1943).

4. Ear and Hearing

4.2 **Electrical Responses from the Primary Acoustic Center of the Frog.** J. Ek and C. L. v. Euler. Nature **152,** 132 (July 31, 1943).

4.4 For references on Deafness see Volta Review.

4.4 **Quinine in Relation to Nerve Deafness.** S. R. Forbes. Ann. Otol., etc., St. Louis **52,** 109–123 (1943).

4.4 **Audiomatic and Word Test Findings. Preliminary Report.** R. P. Guilder. Ann. Otol., etc., St. Louis **52,** 25–33 (1943).

4.4 **Interpretation of Hearing Tests.** C. E. Kinney. Laryngoscope, St. Louis **53,** 223–231 (1943).

4.4 **The Otoscopic Picture in Deafness.** W. Mueller. Ann. Otol., etc., St. Louis **52,** 20–24 (1943).

4.5 **Acoustic Sound Filtration and Hearing Aids.** F. M. Grossman. Arch. Otol. **38,** 101–112 (Aug. 1943).

4.6 **How Well Do I Hear?** M. B. Gardner. Bell Lab. Rec. **22,** No. 1, 6–11 (Sept. 1943).

5. Applied Acoustics, Instruments, and Apparatus

5.1 **Acoustic Stethoscope; detects sounds within the body heretofore unheard.** Sci. Amer. **169,** 131–132 (Sept. 1943).

5.2 **Noise Measurements in Vacuum Tubes.** J. J. DeBuske. Bell Lab. Rec. **21,** No. 12, 456–458 (Aug. 1943).

5.4 **Torsional Vibration Analysis with the Type 736-A (General Radio Corporation) Wave Analyzer.** I. G. Easton. Gen. Radio Experimenter **18,** No. 3, 7–8 (Aug. 1943).

5.4 **An Application of the Cathode-Ray Oscillograph to the Measurement of the Wave-Length of Sound.** G. N. Patchett. Proc. Phys. Soc., Lond. **55,** 324–325 (July 1, 1943).

5.4 **The Noise Primer. Part XII. Analysis of Vibration. Part XIII. How to Use the Vibration Analyzer.** H. H. Scott. Gen. Radio Experimenter **18,** No. 2, 1–5 (July, 1943).

5.4 **Audiofrequency Spectrometer with Inertia-Free Switches.** P. Vetterlein. Z. techn. Phys. **23,** 17–24 (Jan. 1942).

5.7 **Precision Stroboscopic Frequency Meter.** E. A. Kent. Electronics **16,** No. 9, 120–121 (Sept. 1943).

5.8 **Loudspeaker with Acoustic Guides, in Sunk Box, Projecting the Sound above Ground at Angle to Horizontal (gives better coverage than vertical radiation, and better high-note reproduction than horizontal).** L. Bialk and H. Benecke. Hochfrequenztechn. u. Elektroakustik **61,** 32 (Jan. 1943).

5.8 **Improved Reproduction by Loudspeakers by Means of Boucherot Coupling.** A. v. Lupke. Z. techn. Phys. **23,** 119–123 (April, 1942).

5.9 **Acoustic Room and Test Apparatus.** Bell Lab. Rec. **22,** No. 1, 15 (Sept. 1943).

5.9 **Acoustic Stethoscope; detects sounds within the body heretofore unheard.** Sci. Amer. **169,** 131–132 (Sept. 1943).

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5.9 **Improved Contact Microphone.** W. Geffcken. Hochfrequenztechn. u. Elektroakustik **60,** 178 (Dec. 1942); Wireless Engineer **20,** Abs. 2165 (1943).

5.9 **An Improved Carbon Microphone.** A. Lauterer. Hochfrequenztechn. u. Elektroakustik **60,** 178 (Dec. 1942); Wireless Engineer **20,** Abs. 2164 (1943).

5.9 **The Measurement of Torsional Vibrations.** R. Stansfield. J. Proc. Instn Mech. Engrs, Lond. **148,** 175–193 (March, 1943).

5.15 **Acoustic Room and Test Apparatus.** Bell Lab. Rec. **22,** No. 1, 15 (Sept. 1943).

5.15 **Torsional Vibration Analysis with the Type 736-A (General Radio Corporation) Wave Analyzer.** I. G. EASTON. Gen. Radio Experimenter **18,** No. 3, 7–8 (Aug. 1943).

5.15 **Accurate Sound-Measuring Equipment Aids in the Reduction of Unwanted Noise, as well as in the Production of Desired Sounds.** W. MIKELSON. Gen. Elect. Rev. **45,** 685–690 (Dec. 1942); Sci. Abs. **A46,** 1388 (1943).

5.16 **Static Charges on Records.** (One paragraph). Wireless World **49,** 165 (June, 1943); Wireless Engineer **20,** Abs. 2162 (1943).

5.16 **Gramophone Record Wear.** R. BOORMAN. Wireless World **49,** 219 (July, 1943).

5.16 **Needle Armature Pick-Up.** G. A. HAY. Wireless World **49,** 137–139 (May, 1943); Sci. Abs. **A46,** 1909 (1943).

5.16 **The M-G-M Recorder and Reproducer Equipment Units.** W. C. MILLER. J. Soc. Mot. Pic. Eng. **40,** 309–326 (May, 1943).

5.16 **Sound Recording at the Signal Corps Photographic Center.** G. C. MISENER. J. Soc. Mot. Pic. Eng. **41,** 226–238 (Sept. 1943).

5.16 **The Siemens Silver-Vapour Process for Gramophone-Record Production.** SIEMENS AND HALSKE. Bull. de l'Assoc. Suisse des Elec. **34,** 263 (May 5, 1943).

5.16 **Acoustic Performance of 16-millimeter Sound Motion-Picture Projectors.** W. F. SNYDER. Circ. U. S. Bur. Stand. No. 439 (1942); Sci. Abs. **A46,** 2167 (1943).

5.17 **Speech Scrambling Methods.** W. W. ROBERTS. Electronics **16,** No. 10, 108–111, 270–278 (Oct. 1943).

5.51 **The Acoustics of Broadcasting Studios.** W. FURRER. Bull. de l'Assoc. Suisse des Elec. **33,** 305–310 (June 3, 1942).

5.51 **Speech Scrambling Methods.** W. W. ROBERTS. Electronics **16,** No. 10, 108–111, 270–278 (Oct. 1943).

6. MUSICAL INSTRUMENTS AND MUSIC

6.1 **Relation Between Dissonance and Context.** P. A. D. GARDNER AND R. W. PICKFORD. Nature **152,** 358 (Sept. 25, 1943).

6.6 **The Problem of the Keyboard Instrument.** L. S. LLOYD. Phil. Mag. **34,** 472–479 (July, 1943).

7. NOISE

7.1 **What To Do about Noise.** Fortune **28,** 14 (July, 1943).

7.7 **Steam-Turbine Vibration.** Marine Engr. Lond. **66,** 96–98 (May, 1943); Sci. Abs. **B46,** 1663 (1943).

7.7 **"White Noise" in Planes.** Science **98,** No. 2535, Suppl. p. 8 (July 30, 1943).

7.7 **Acoustics and the Quiet Train Ride.** W. A. JACK. Trans. Amer. Inst. Elect. Engrs, Suppl. **61,** 382–392 (June, 1942); Sci. Abs. **A46,** 1908 (1943).

9. SPEECH AND SINGING

9.5 **Sibilant Speech Sounds.** B. F. MILLER. Electronic Eng. **16,** 69–70 (July, 1943); Sci. Abs. **A46,** 2168 (1943).

9.5 **Data on Resonance of Vowels.** T. VON TARNOCZY. Naturwissenschaften **31,** 66 (Jan. 29, 1943).

10. SUPERSONICS (ULTRASONICS)

10.3 **A Mineral Survey for Piezoelectric Materials.** W. L. BOND. Bell System Tech. J. **22,** 145–152 (July, 1943).

10.3 **Methods for Specifying Quartz Crystal Orientation and Their Determination by Optical Means.** W. L. BOND. Bell System Tech. J. **22,** 224–262 (July, 1943).

10.3 **Quartz Crystal Applications.** W. P. MASON. Bell System Tech. J. **22,** 178–223 (July, 1943).

10.3 **Force-Constants and Normal Modes of the Totally Symmetric Vibrations in Quartz at Room Temperature.** B. D. SAKSENA. Proc. Indian Acad. Sci. **A16,** 270–277 (Oct. 1942). Sci. Abs. **A46,** 1383 (1943).

10.3 **Supersonics for Communication.** S. J. WEITZER. QST **27,** No. 10, 9–13 (Oct. 1943).

10.4 **Absorption Measurements in Ultrasonics.** H. BORN. Z. Phys. **120,** 383–396 (Feb. 23, 1943).

10.5 **Dispersion of Sound Velocity in Some Alcohols.** G. R. RENDALL. Proc. Indian Acad. Sci. **A16,** 369–378 (Dec. 1942); Sci. Abs. **A46,** 1387 (1943).

10.5 **Absorption Measurement of Ultrasonics in Electrolytic Solutions.** W. RÜFER. Ann. Phys., Lpz. **41,** 301–312 (Apr. 1942).

10.6 **Some Physical Procedures Used in Ceramic Research.** G. A. BOLE AND G. A. LOOMIS. J. Appl. Phys. **14,** 443–450 (Sept. 1943). (Contains material on sonic properties and also on ultrasonic vibration and ceramics.)

11. WAVES AND VIBRATIONS

11.3 **Some Physical Procedures Used in Ceramic Research.** G. A. BOLE AND G. A. LOOMIS. J. Appl. Phys. **14,** 443–450 (Sept. 1943).

11.3 **Propagation of Elastic Waves through Electrolytic Solutions.** A. K. DUTTA AND B. B. GHOSH. Indian J. Phys. **17,** 19–25 (Feb. 1943).

11.3 **An Application of the Cathode-Ray Oscillograph to the Measurement of the Wave-Length of Sound.** G. N. PATCHETT. Proc. Phys. Soc., Lond. **55,** 324–325 (July 1, 1943).

11.3 **Vibration Properties of Rubber-Like Materials. Dependence on Temperature.** R. B. STAMBAUGH. Industr. Engng Chem. (Ind. ed.) **34,** 1358–1365 (Nov. 1942); Sci. Abs. **A46,** 1384 (1943).

11.4 **The Freely Oscillating Piston Diaphragm.** A. SOMMERFELD. Ann. Phys., Lpz. **42,** 389–420 (Feb. 7, 1943); Wireless Engineer **20,** 2404A (1943).

11.4 **Computation of the Sound Field Immediately in Front of a Circular Membrane.** H. STENZEL. Ann. Phys., Lpz. **41,** 245–260 (April, 1942).

11.5 **Emission of Sound by a Moving Source.** D. I. BLOCHINTZEV. J. Phys. U.S.S.R. **6,** 230 (1942).

11.6 **Reverberation in Small Glass Tubes.** S. M. Cox. Nature **152,** 357–358 (Sept. 25, 1943).

11.7 **Quartz Crystal Applications.** W. P. MASON. Bell System Tech. J. **22,** 178–223 (July, 1943).

11.7 **Vibration Properties of Rubber-Like Materials. Dependence on Temperature.** R. B. STAMBAUGH. Industr. Engng Chem. (Ind. ed.) **34,** 1358–1365 (Nov. 1942); Sci. Abs. **A46,** 1384 (1943).

11.7 **The Measurement of Torsional Vibrations.** R. STANSFIELD. J. Proc. Instn Mech. Engrs, Lond. **148,** 175–193 (March, 1943).

11.7 **Steam-Turbine Vibration.** Marine Engr, Lond. **66,** 96–98 (May, 1943); Sci. Abs. **B46,** 1663 (1943).

11.7 **Measurement of the Fine Structure of Acoustic Resonance with a Hot Wire Meter.** A. LOEBENSTEIN. Helv. Phys. Acta **16** (Jan. 1943).

11.7 **A Method for Measuring Amplitudes of Vibration of Rotating Shafts.** J. A. MITCHELL. J. Sci. Instrum. **20,** 134 (Aug. 1943).

11.7 **Electrical Circuit Analysis of Torsional Oscillations.** L. A. PIPES. J. Appl. Phys. **14,** 352–362 (July, 1943).

11.7 **The Vibration Characteristics of "Free-Free" Circularly Curved Bars.** W. A. PLISKIN, J. E. EDWARDS, AND F. P. BUNDY. J. Appl. Phys. **14,** 410–417 (Aug. 1943).

11.7 **Force-Constants and Normal Modes of the Totally Symmetric Vibrations in Quartz at Room Temperature.** B. D. SAKSENA. Proc. Indian Acad. Sci. **A16,** 270–277 (Oct. 1942); Sci. Abs. **A46,** 1383 (1943).

Review of Acoustical Patents

ROBERT W. YOUNG
C. G. Conn, Ltd., Elkhart, Indiana

Printed copies of patents are furnished by the Patent Office at a cost of 10¢ each. Address all communications to: The Commissioner of Patents, Washington, D. C. Remittance may be made by money order, certified check, cash, or special coupons which are sold in blocks of twenty or books of one hundred.

The decimal numbers appearing before titles are those which identify the headings being used in the analytic subject index of this journal. The Patent Office classification given in parentheses with each patent entry is outlined in the "Manual of Classification of Patents" which is obtainable from the Superintendent of Documents for $1.50.

Unless otherwise indicated, patents listed have been issued by the United States Patent Office.

Reviewers

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R. W. YOUNG, *C. G. Conn, Ltd., Elkhart, Indiana*

2,285,924

2.4 SOUND DEADENING MATERIAL AND METHOD

Gustaf A. Halfvarson, assignor to Westinghouse Electric & Manufacturing Company.
June 9, 1942, 9 Claims (Cl. 189–34).

This patent discloses a method for deadening the vibration of a metal surface by attaching thereto a metal disk or plate of the order of 0.025" thickness into which a number of slits have been cut at regularly spaced intervals. The cuts are made by shearing the metal (Fig. 1), then flattening it out so that the ragged edges of the cut are in contact (Fig. 2). Deadening action is believed to reside in the segmental vibration of the disk and the setting up of

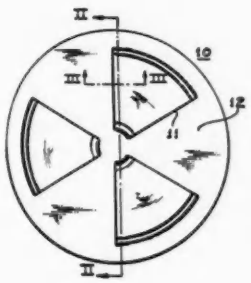


FIG. 1.

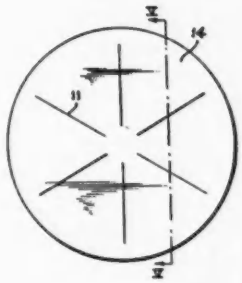


FIG. 2.

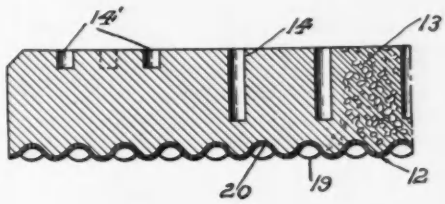
friction by the resulting differential motion of the contacting edges of each slit. The device is applied particularly to quieting the compressor unit of a domestic refrigerator.—H. J. S.

2,292,444

2.4 TILE

Osborne Haydon and Thompson P. Finefrock, assignors to The Celotex Corporation.
August 11, 1942, 3 Claims (Cl. 72–18).

An acoustic tile produced from a gypsum plaster mix poured on and bonded to a paper reinforcing backing.



The paper contains regularly spaced preformed dimples or indentations which bond to the gypsum in such a way as to prevent warping as the gypsum sets.—H. J. S.

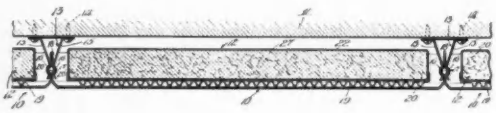
2,293,351

2.4 SOUND ABSORBING CONSTRUCTION

Richard N. Meginnity, assignor to The Celotex Corporation.
August 18, 1942, 4 Claims (Cl. 20–4).

This invention relates to the type of acoustic tile characterized by a perforated metal pan in which is placed a wrapped sound absorbent pad, and in particular to a

method for supporting and spacing the pad away from the pan. This is done by means of a coil spring **19** which



before use is fully collapsed. In use, the spring is pulled out and attached to the pad by hooking into the wrapping membrane.—H. J. S.

2,295,155

2.4 METHOD OF MAKING SOUND ABSORBING MATERIAL

George B. Brown and Osborn Ayers, assignors to Johns-Manville Corporation.
September 8, 1942, 7 Claims (Cl. 25–155).

This patent describes a method of making an acoustic tile composed of ground natural sponge, asbestos fiber, and Portland cement. The sound absorbing properties are derived chiefly from the sponge, the asbestos fiber and cement serving as a skeletonized binder structure.—H. J. S.

2,301,538

2.4 SOUND INSULATING CONSTRUCTION

Reynolds Guyer and Henry E. Hartig, assignors to Waldorf Paper Products Company.
November 10, 1942, 11 Claims (Cl. 154–45).

This is an acoustic tile made, in its simplest form, of a single square sheet of double-faced corrugated paper box

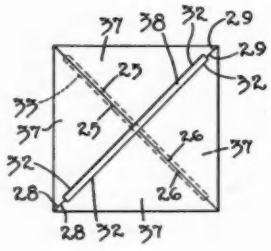


FIG. 1.

board, as shown in Fig. 3. The corners **37** of the blank are folded back along diagonal scored lines **34, 35** so that the finished tile consists of a double thickness of board. A slot **33** is cut in the face of the tile at right angles to the corrugations, which are thus open to the room. The corrugations act as channels which, due to a double fold, are not closed at the edge of the tile but lead to a similar slot on the back surface opening into the air space behind the tile. Incident sound waves force air into the corrugations through the face slot, absorption taking place partly through the air flow resistance in the corrugations and partly through diaphragmatic vibration of the tile as a whole. It is claimed

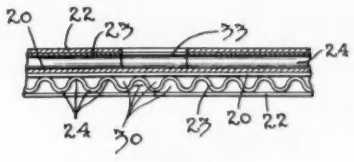


FIG. 2.

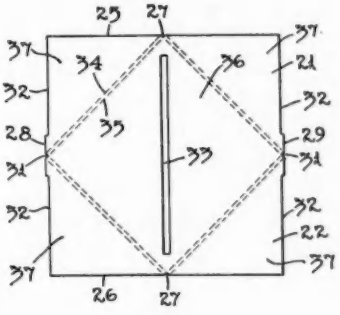


FIG. 3.

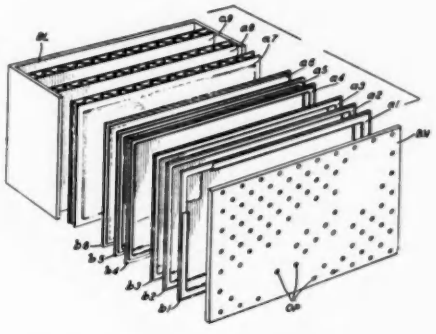
that the channels are long enough to provide effective sound absorption at comparatively low frequencies, due to resonance.—H. J. S.

2,308,869

2.4 ACOUSTIC WALL PANEL

Helmuth Eckardt, assignor to Bell Telephone Laboratories, Incorporated.
January 19, 1943, 7 Claims (Cl. 181–0.5).

This patent describes a sound-absorbing wall construction involving a multiplicity of diaphragms stacked in light contact with each other. These are made of paper or metal foil and increase in weight progressively from face



to back of the structure. The assembly is contained in a sheet metal casing and may be faced with a perforated

board. Sound absorption is effected by the mechanical friction between the contacting diaphragms. The figure is an exploded view of the construction.—H. J. S.

2,312,776

2.4 ACOUSTICAL WALL COVERING

Kenneth S. Rankin, assignor to Acousticwall Limited.
March 2, 1943, 5 Claims (Cl. 106–122).

An acoustical material intended either for plastic application or for casting in tile form, having as dry ingredients calcined diatomaceous earth, glass wool, asbestos fiber, and titanium dioxide. The liquid components are distilled yellow glycerine, a saponified sizing used as a binder, and water. High coverage and sound absorption are derived from the large amount of water used in the mix.—H. J. S.

2,298,326

2.9 VIBRATION AND SOUND DAMPING MATERIAL

Erwin A. Worm, Jr., assignor to Armstrong Cork Company.
October 13, 1942, 5 Claims (Cl. 154–44).

This patent relates to impregnated felt of the type used for damping the vibration of metal panels. A manufacturing process is described by means of which both the over-all flexibility of the felt is increased and the relation between the lateral and longitudinal flexibility of the sheet is made more uniform. This effect is achieved by feeding the sheet through pairs of differentially driven rollers which form pores on the two surfaces.—H. J. S.

2,308,302

2.9 ACOUSTICS

Theodore M. Prudden.
January 12, 1943, 3 Claims (Cl. 154–44).

A vibration damping treatment for application to vibrating metal surfaces such as automobile bodies. The treatment consists of a sheet of asphalt impregnated paper (slater's felt) folded into pleats or leaves. The sheet proper is adhered to the vibrating metal surface, the pleats being

held down rather loosely. When the metal panel vibrates "it causes the pleats to be agitated or fluttered at their own inaudible rate to move or fan the surrounding air and cause the vibration of the panel to be damped." A feature of the invention is the closer spacing of the pleats near the center of a panel where the amplitude of vibration is greatest.—H. J. S.

2,310,154

2.9 ACOUSTIC SCREEN

Vesper A. Schlenker.
February 2, 1943, 4 Claims (Cl. 181–31).

The subject of this invention is a screen designed to transmit sound very efficiently while affording an impervious barrier to direct air flow and physical penetration.

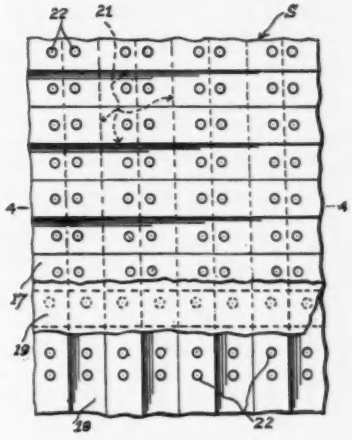


FIG. 1.

The screen consists of a thin diaphragm **19** of metal or plastic of the order of 0.001" thickness sandwiched between two rigid perforated corrugated plates **17, 18,** the corrugations of the two plates being at right angles to each other. The diaphragm is clamped at each intersection of the corrugations and is thus subdivided into a multiplicity of small, square sub-diaphragms **21.** The transmission loss

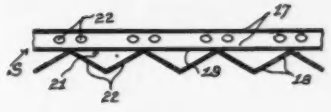


FIG. 2.

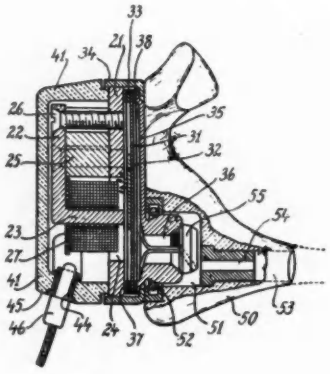
is stated to be about 1 decibel for high frequencies and upwards of 5 decibels for the lower frequencies, a characteristic particularly favorable for speech transmission. Since by choice of materials the screen can be made either transparent, translucent, or opaque, it is adaptable to varied uses, as in the Catholic confessional, ticket windows, etc.—H. J. S.

2,325,590

4.5 EARPHONE

Richard W. Carlisle and Alfred J. Mastropoie, assignors to Sonotone Corporation.
August 3, 1943, 8 Claims (Cl. 179–107).

Although simplified for manufacture, this midget magnetic earphone embodies several means for adapting it to



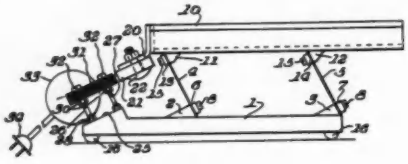
the particular needs of the hard-of-hearing person in whose ear it is to be inserted. For example, a change in the thickness of the armature **32** from 0.030 inch to 0.015 inch can increase the resonant frequency from 1100 to 1800 cycles/sec.—L. W. S.

2,305,943

5.1 ELECTRICALLY OPERATED VIBRATORY APPARATUS

Carl S. Weyandt.
December 22, 1942, 6 Claims (Cl. 172–126).

When apparatus such as a vibratory conveyor is driven by alternating current through an ordinary electromagnet, the conveyor vibrates at a rate twice that of the power supply. As disclosed in this patent, this frequency doubling is avoided by the use of a permanent magnet **21** within the oscillating field of electromagnet **31.** The trough **10** is supported on leaf springs **4** and **5** of such a stiffness that



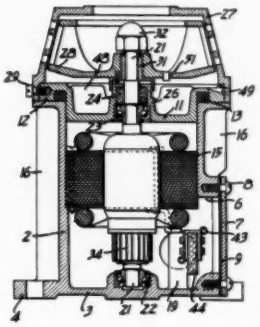
the natural frequency of vibration in the horizontal plane is about $\frac{2}{3}$ that of the alternating power supply.—R. W. Y.

2,314,260

5.1 SIREN

Evan D. Williamson, assignor to E. D. Bullard Company.
March 16, 1943, 4 Claims (Cl. 177–7).

This signalling device, intended for marine installation, has its sealed motor in intimate contact with the case so that the cooling fins **16** are effective in carrying off the heat. Arcuate radial fins **48** directly under the rotor **28** conduct heat to air which passes out ventilating openings



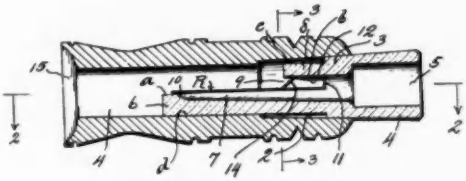
49. Inlets **51** may be provided to assist the blower action produced by the motion of the rotor.—R. W. Y.

2,317,458

5.1 WIND SOUNDING DEVICE

George L. Herter.
April 27, 1943, 3 Claims (Cl. 46–180).

A novel feature of this sound-producing device (for simulating the call of a wild duck) is that the reed **R** is at



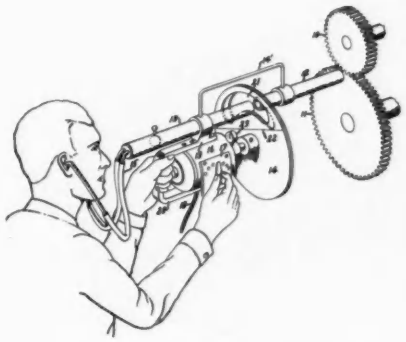
all times under tension as a result of its contact with member **14.** The slot **9** in plug **3** is of such a size that the reaction of **14** serves to keep the reed assembly in position. —R. W. Y.

2,324,305

5.1 SOUND STROBOSCOPE

Lowell M. Kurtz, assignor to General Electric Company.
July 13, 1943, 4 Claims (Cl. 88–14).

Acoustical counterpart of the "stroboscope" consisting of a transmission pipe **12–13** and a slotted disk for periodically interrupting the passage of sound. Visual observations may be simultaneously conducted by sighting through the slot **21.** The speed of motor-driven disk is controlled by



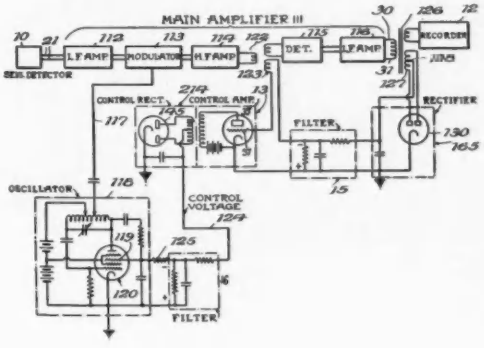
means of rheostat **17.** Another version using a microphone and a flashing source of light is illustrated.—B. B. B.

2,286,106

5.10 APPARATUS FOR AND METHOD OF RECEIVING AND RECORDING VIBRATIONS

Otto F. Ritzmann, assignor to Gulf Research and Development Company.
June 9, 1942, 7 Claims (Cl. 177–352).

A system for controlling gain of amplifiers used in geophysical prospecting. It also describes means of controlling frequency response of these amplifiers by means of the



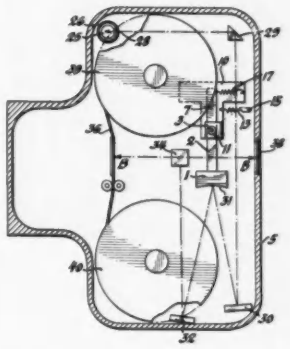
rectified output. These systems incorporate carrier amplifiers in which the carrier frequency is controlled by the signal amplitude.—G. W. D.

2,293,288

5.10 VIBRATION INDICATOR

Charles W. Gadd, assignor to General Motors Corporation.
August 18, 1942, 3 Claims (Cl. 73–51).

This seismometer is so designed as to measure horizontal displacements while minimizing effects of tilt. Two pendulums, one inverted, are coupled by springs. These two pendulums are concentric and balanced against vertical accelerations, but not against horizontal displacements.



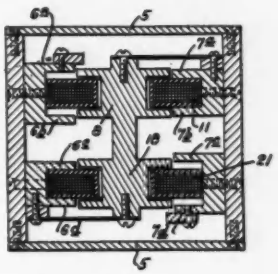
The system uses optical indicating and recording methods. —G. W. D.

2,303,413

5.10 SEISMOMETER

Harold W. Washburn, assignor to Consolidated Engineering Corporation.
December 1, 1942, 9 Claims (Cl. 177–352).

This patent describes a design for a variable reluctance seismometer for use in geophysical prospecting. The magnetic forces are carefully balanced. By suitable disposition



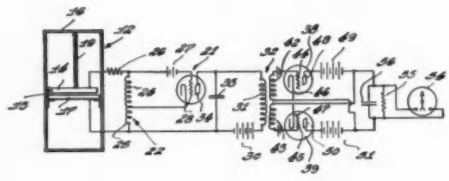
of the magnetic material and the coil, high efficiency is obtained, thus being great enough to supply electrical damping.—G. W. D.

2,309,560

5.10 METHOD AND APPARATUS FOR MEASURING AND RECORDING VIBRATIONAL EFFECTS

William Robertson Welty, assignor to Olive S. Petty.
January 26, 1943, 3 Claims (Cl. 171–95).

The specification describes three electronic circuits containing one or more integrating meshes. It is intended that



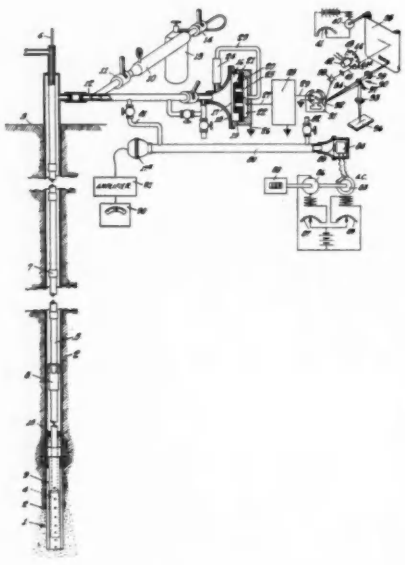
these circuits be used to modify the signals from seismometers before recording. The claims cover a rather unusual amplifier circuit and one integrating mesh as shown in the figure.—G. W. D.

2,310,559

5.10 VIBRATION TRANSLATING MEANS

Cranford P. Walker.
February 9, 1943, 12 Claims (Cl. 177–352).

According to this system for determining level of fluid in a well a compressional wave is propagated in the space between the tubing and casing. The energy returned by



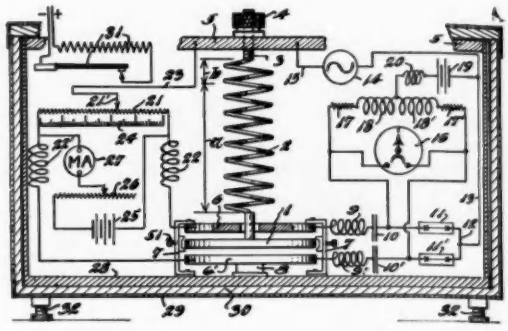
reflection from tubing collars and the surface of the fluid is used to actuate a microphone. The signals from this unit are amplified and recorded on an oscillograph.—G. W. D.

2,316,915

5.10 APPARATUS FOR AMPLIFYING AND MEASURING SMALL DISPLACEMENTS

Orley H. Truman.
April 20, 1943, 12 Claims (Cl. 265–1.4).

This gravity meter uses a capacitance variation resonance bridge to measure displacement and electrostatic forces to restore system to balance. It also includes a spring demagnifier to regain zero setting and a bimetallic



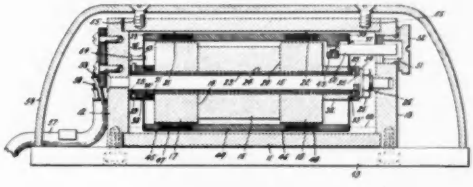
temperature compensator using a similar spring system. —G. W. D.

2,316,616

5.10 VIBRATION RESPONSIVE DEVICE

Frederic K. Powell, assignor to General Electric Company.
April 13, 1943, 5 Claims (Cl. 171–209).

Specification shows design for a moving coil generator type of seismometer. Two coils mounted on a common form



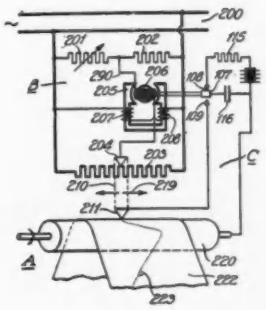
move in two-series gaps. The coils and forms act as steady mass and are mounted by two W-shaped spiders which serve as restoring springs and as leads for the coils.—G. W. D.

2,321,605

5.15 MEASURING SYSTEM

George Keinath.
June 15, 1943, 15 Claims (Cl. 171–95).

A bridge circuit is arranged to be balanced by a motor driven contact **204** on an adjustable impedance **203.** Just after balance is passed the charge on condenser **116** is transferred through contact **109** to stylus **211** and the resulting current produces a mark on the electrochemical paper **222** which is being moved steadily by roller **220.** The position of this mark is related to that impedance value which just balances the bridge and is thus a record of the variable impedance **201.** Impedance **201** may in



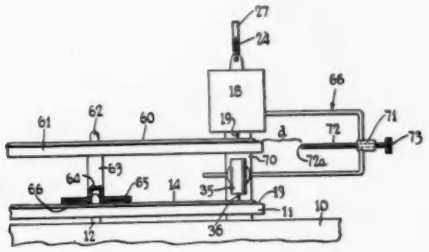
turn be dependent on some other variable such as temperature. The reciprocating connection **219** may be replaced by a rotating one, as in Patent Re. 22,293.—R. W. Y.

2,314,345

5.16 PHONOGRAPH DEVICE

Alphonse Cortella, assignor to Thomas K. Patterson.
March 23, 1943, 6 Claims (Cl. 274–13).

The object of this invention is to utilize in home recording a pregrooved disk **14** as the tracking guide for making a new record. When the tracking disk is the same size or



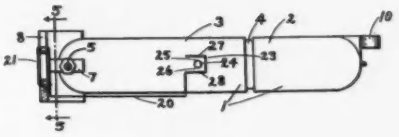
smaller than the one to be cut, a "two-deck" arrangement may be employed as shown in the figure. If the tracking disk is larger, both may be carried on the same turntable and the tracking device attached alongside the cutter arm.—L. W. S.

2,316,637

5.16 PHONOGRAPH RECORD SCANNING DEVICE

Lincoln Thompson, assignor to The Soundscriber Corporation.
April 13, 1943, 8 Claims (Cl. 274–1).

In reproducing embossed records difficulty is encountered since any slight jar tends to cause the pick-up stylus to leave the groove. When a pivoted tone arm is used and the stylus is outside of the tangent groove, because of friction between stylus and groove there is a force which urges the reproducer toward the outside of the record. When the stylus is inside the tangent groove the force is toward the center. To overcome this friction force component a light spring **20** is fastened to stationary post **8** behind the pivot point of the tone arm by means of loop



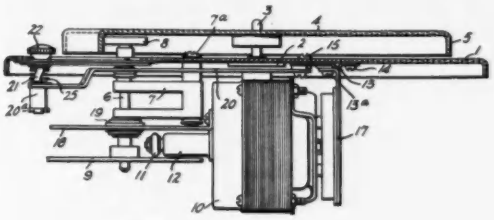
21 and by a **U** around post **24.** Clearances **25** and **26** allow a neutral position a few degrees on each side of the tangent groove. When the neutral zone is passed the spring bears against post **24** on the tone arm thus supplying a force in opposition to that due to friction between stylus and groove.—L. W. S.

2,316,857

5.16 PHONOGRAPH DRIVE MECHANISM

Willard J. Green, assignor to Philco Radio and Television Corporation.
April 20, 1943, 10 Claims (Cl. 74–194).

This invention relates to a variable speed phonograph turntable drive mechanism. The turntable is rim driven through wheel **8** and friction disk **9.** The speed is changed by moving motor **11** in a horizontal plane along the radius of friction disk **9** by means of a lever **20** and knob **22** which moves in a slot. Positions corresponding to two speed ranges such as 33⅓ and 78 r.p.m. lie at the extreme ends of the slot. Small changes in speed about these extremes



may be made by turning knob **22,** pivot point **20a** being eccentrically connected with knob **22** by means of arm **21.**—L. W. S.

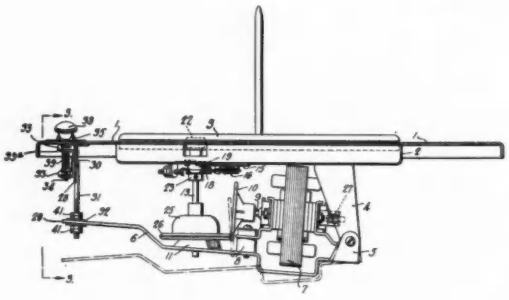
2,316,858

5.16 TURNTABLE DRIVE MECHANISM

Elmer O. Thompson, assignor to Philco Radio and Television Corporation.
April 20, 1943, 7 Claims (Cl. 74–194).

This variable speed turntable is similar in purpose to the one described in the preceding patent No. 2,316,857.

Here the speed change is accomplished by pivotably mounting the motor and friction disk, and moving same



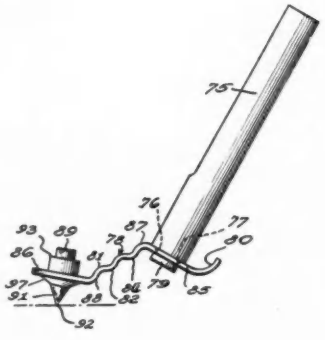
in a vertical plane so as to obtain relative displacement of the driven wheel **26** along the radius of the friction disk **10**.—L. W. S.

2,320,416

5.16 STYLUS FOR REPRODUCERS

Roy Dally, assignor to Webster Electric Company. June 1, 1943, 8 Claims (Cl. 274–38).

The shank of a phonograph reproducer stylus is provided with a flat spring **78** on which is mounted the stylus tip.



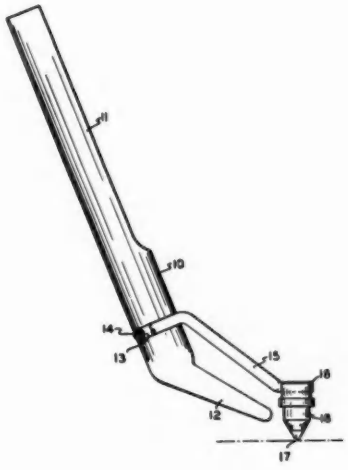
This results in a stylus with controlled vertical compliance and serves to protect the stylus tip from impacts. Damping material may be applied to the spring.—L. W. S.

2,325,343

5.16 SOUND REPRODUCING STYLUS

Robert E. Semple, assignor to The Astatic Corporation. July 27, 1943, 13 Claims (Cl. 274–38).

The vertically compliant mounting for the stylus tip in this phonograph reproducer stylus is in the form of a



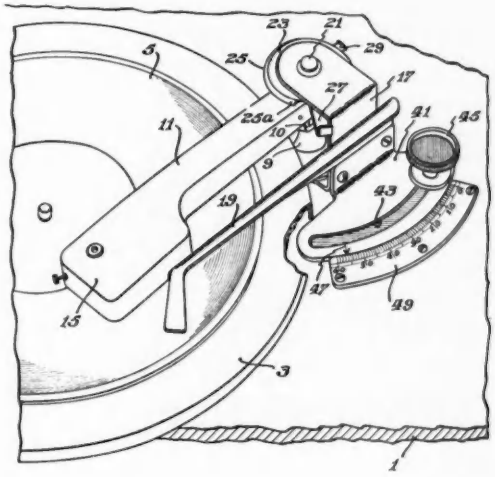
round wire **15.** In addition the shank is flattened and bent forward to constitute a guard for the stylus tip against its dropping upon and colliding with the edge of the record. —L. W. S.

2,325,708

5.16 PHONOGRAPH

Frank E. Runge, assignor to Radio Corporation of America. August 3, 1943, 8 Claims (Cl. 274–14).

This is a groove spotting device which may be used for repeating a particular portion of a phonograph record. The pick-up is moved by means of lever **27** working against



an adjustable stop **19.** The pick-up is raised and lowered by means of roller **29** acting on cam **25** which is associated with lever **27.**—L. W. S.

2,326,389

5.16 PHONOGRAPH STYLUS

Sherman E. Pate, assignor to Permo Products Corporation.
August 10, 1943, 4 Claims (Cl. 274–38).

In this phonograph reproducing stylus damping material is used between the slender portion of the stylus and a

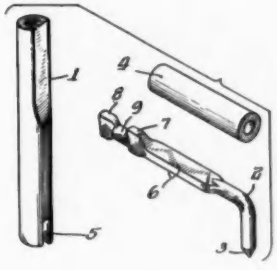
tube surrounding same to control the frequency response and resonance.—L. W. S.

2,326,424

5.16 PHONOGRAPH STYLUS

Lloyd J. Andres, assignor to Permo Products Corporation.
August 10, 1943, 2 Claims (Cl. 274–38).

To simplify the construction of an offset reproducer stylus the flattened ends **7** and **8** are fitted into slot **5** of the hollow shank **1** and then held securely in place by swaging or spinning a spherical end on the shank. This

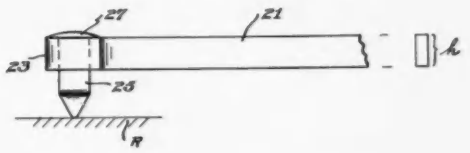


may be compared with the round wire type (Pat. 2,325,343) and the flat spring type (Pat. 2,320,416). Sleeve **4** is of damping material which is fitted over **6**.—L. W. S.

2,326,460

5.16 SIGNAL TRANSLATING APPARATUS

Harold J. Hasbrouck, Jr., assignor to Radio Corporation of America.
August 10, 1943, 5 Claims (Cl. 179–100.41).



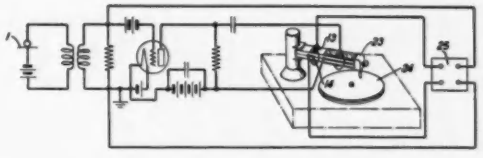
According to this disclosure there are cases in which it is desirable that a reproducing stylus have greater stiffness in a plane normal to that of the record than in a plane parallel to the plane of the record, so that it will have sufficient stiffness to support the weight of the pick-up yet retaining desired flexibility in a lateral direction. Therefore, member **21** may be made of spring steel of the order of 0.007 inch thick with its height approximately 0.012 inch.—L. W. S.

2,328,478

5.16 PIEZOELECTRIC TRANSDUCER

Warren P. Mason, assignor to Bell Telephone Laboratories, Incorporated.
August 31, 1943, 5 Claims (Cl. 179–100.4).

The object of this invention is to minimize the effect of any non-linear characteristics of piezoelectric transducers such as those of the Rochelle salt type. This is accomplished



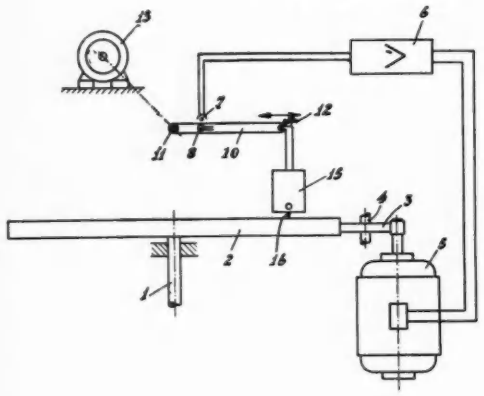
by providing on the electromechanical motors an additional pair of electrodes, the voltage on which is applied as negative feedback to the driving amplifier.—L. W. S.

2,328,515

5.16 PHONOGRAPH TURNTABLE DRIVING DEVICE

Marius Leonard van Overeem; vested in Alien Property Custodian.
August 31, 1943, 7 Claims (Cl. 274–9).

This is a constant groove speed turntable drive mechanism wherein the turntable is driven by a synchronous motor **5**. This motor is supplied with a variable frequency



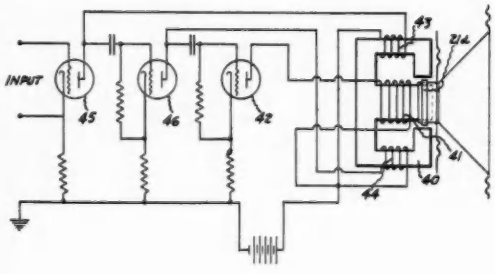
current generated by interrupting the light beam falling upon a photoelectric cell. The light chopper consists of a perforated elastic band **10** which runs between rollers **11** and **12,** and is driven by a fixed speed synchronous motor **13.** Roller **12** moves in conjunction with cutting or reproducing head **15,** thus varying the length of the elastic band, and the rate at which the light beam is interrupted. Consequently the turntable is driven at a speed dependent upon groove position.—L. W. S.

2,328,836

5.8 LOUDSPEAKER AND CIRCUIT THEREFOR

John J. Moynihan, assignor of one-half to Joseph B. Brennan.
September 7, 1943, 11 Claims (Cl. 179–1).

In this loudspeaker the plate current of the output stage furnishes both the polarizing field and signal current to the loudspeaker. The signal portion of the plate current



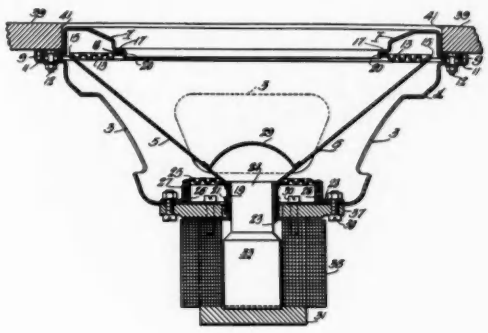
induces corresponding variations in a short-circuited voice coil. Additional polarizing magnetomotive force is said to be obtainable by having the plate current of preceding amplifier pass through windings on the same magnetic structure. No account is taken of the positive or negative feedback which inheres in such an arrangement.—V. S.

2,329,560

5.8 ACOUSTIC DEVICE

John D. Seabert, assignor to Radio Corporation of America.
September 14, 1943, 6 Claims (Cl. 181–31).

The beaded annulus supporting the outer edge of the cone of direct radiator loudspeakers adds considerably to



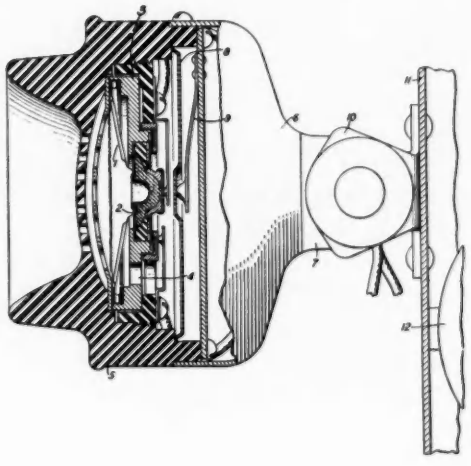
the mounting diameter. By the internal support of this invention, the available space may be utilized more completely.—V. S.

2,320,433

5.9 TELEPHONE TRANSMITTER

Alfred Herckmans, assignor to Bell Telephone Laboratories, Incorporated.
June 1, 1943, 5 Claims (Cl. 179–123).

Conventional telephone transmitter associated with vibration sensitive diaphragm **8.** The latter serves to rein-



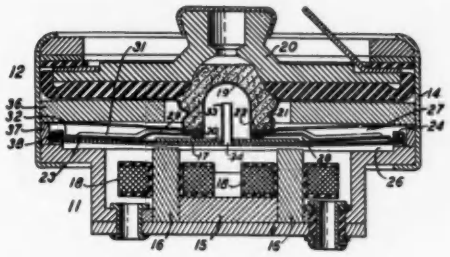
force the bell sounds produced in the coin collector.—B. B. B.

2,325,117

5.9 VIBRATION TRANSLATING DEVICE

George J. V. Faley, assignor to Bell Telephone Laboratories, Incorporated.
July 27, 1943, 5 Claims (179–171).

A system for transferring vibrations (from a receiver to carbon button for purpose of amplification) employing two



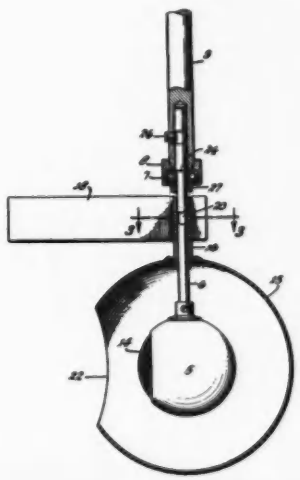
closely-spaced diaphragms coupled together by the stiffness of air trapped therebetween. Resonant peak at high frequency is controlled by association with an acoustic anti-resonant network. Low frequency transmission is prevented by decoupling through the use of a parallel inertance.—B. B. B.

2,325,424

5.9 WINDSHIELD FOR MICROPHONES

Michael Rettinger, assignor to Radio Corporation of America.
July 27, 1943, 8 Claims (Cl. 179–188).

Windshield for microphones consisting of a foraminous screen **15** provided with opening **22** for free passage of sound. Also a vane **18** capable of rotating the microphone



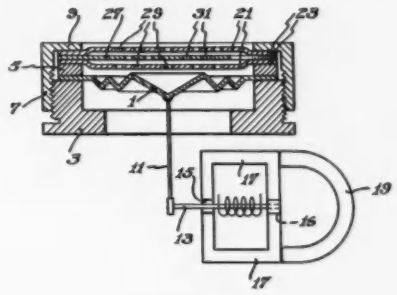
and/or the screen in such a manner that opening **22** is away from the direction of wind.—B. B. B.

2,325,688

5.9 SOUND TRANSLATING APPARATUS

Daniel O. Landis, assignor to Radio Corporation of America.
August 3, 1943, 3 Claims (Cl. 179–184).

Flap valve **27** between perforated plates **21** permits transmission of sound to diaphragm **1** but closes apertures



29 when microphone is subjected to gunblast. The diaphragm is thereby protected.—B. B. B.

2,317,428

6.1 MANUFACTURE OF HARMONICAS

Charles E. Wetzler and Paul F. Boehm, assignors to The United States Harmonica Corporation.
April 27, 1943, 12 Claims (Cl. 29–34).

According to this method of assembling harmonicas the reeds **710** are punched in a single plate which is inserted

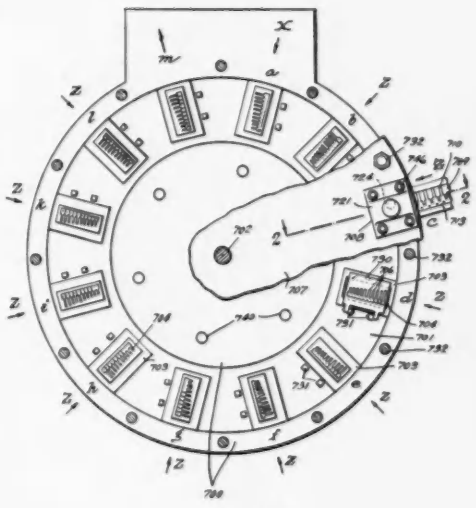


FIG. 1.

in channel **709.** Reed plates **704,** from which rivets **712** have previously been extruded, are set into bolster blocks

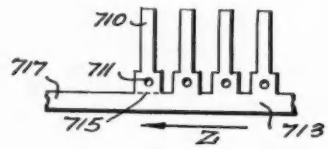


FIG. 2.

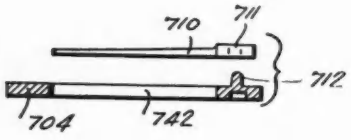


FIG. 3.

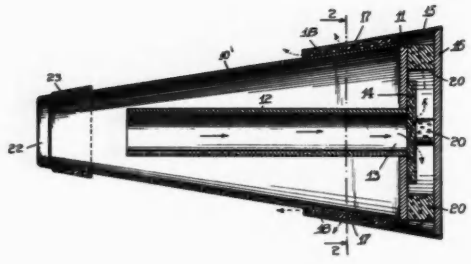
703. At each station **a** to **m** a reed is sheared off the strip along line **715** and held in proper alignment while being riveted in place.—R. W. Y.

2,318,535

6.3 MUTE

Charles Spivak, assignor to Micro Musical Products Corporation.
May 4, 1943, 16 Claims (Cl. 84–400).

This mute is intended to reduce the volume of sound from a trumpet, for example, without interfering with the tone quality thereof. Since gasket **23** forms a tight seal in



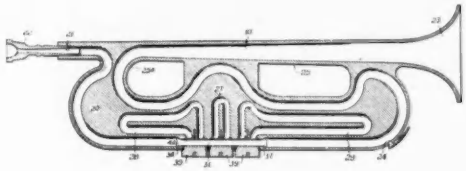
the bell of the instrument in which the mute is used, the air passes out through tube **12,** sound absorbing material **14,** past spacers **20,** through sound absorbing material **18,** and out apertures **17.** The end plates **11** and **16** are of wood or of some other material adapted to vibration. There are in effect two chambers connected by the tube **12** whose length may be modified to vary the muting effect.—R. W. Y.

2,320,202

6.3 MUSICAL INSTRUMENT

Josephus Thompson, assignor of one-third to Grossman Music Company.
May 25, 1943, 7 Claims (Cl. 84–388).

The entire air column in this musical instrument of the trumpet type lies in one plane. The channels **27, 31** associated with the valves are square in cross section, but the other channels are circular. The valves **40** themselves are in the shape of an inverted **T** and are operated by push rods lying at one side of the principal plane of the instrument. When a valve is depressed the head of the **T** seals against the base **39;** the stem of the **T** deflects the air



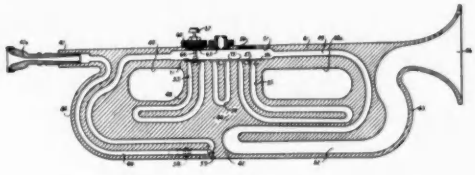
through the valve channel. The instrument is designed to be made of a plastic. How tuning is to be accomplished is not clear, since no tuning or valve slides are provided.—R. W. Y.

2,320,203

6.3 MUSICAL INSTRUMENT

Josephus Thompson and Morton S. Brockman, assignors of one-sixth to said Thompson and five-sixths to Grossman Music Company.
May 25, 1943, 17 Claims (Cl. 84–388).

In contrast with the instrument disclosed in Patent 2,320,202 the present trumpet has its valves near the top. The molded plastic halves of the instrument are symmetrical so that they may be attached together along the median plane. The valve plates **71** are normally held closed by a spring, but when the valve stem **66** is depressed the plates are caused to rotate, thereby opening the side branches and obstructing the direct air path, which is of square cross section. In an alternative form valves of



another type and the associated tubing are offset, all of which requires more complicated molds.—R. W. Y.

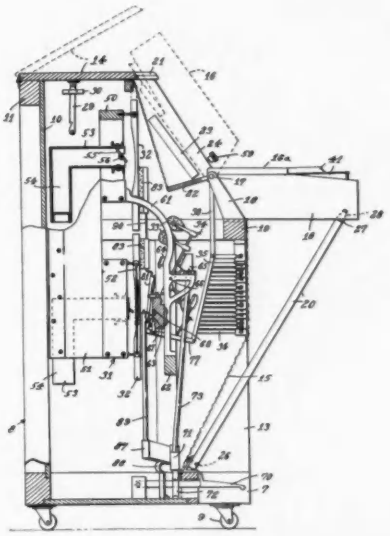
2,315,812

6.4 PIANO-VIBRAPHONE

Gerald A. O'Connell and Carl M. Larson.
April 6, 1943, 9 Claims (Cl. 84–410).

"A salient feature of the present instrument is the utilization of an upright piano type action modified only

to the extent necessary to adapt it to having the hammers strike the vertically hung bars of the xylophone part of the instrument, whereby to obtain the desired ease and speed of playing, sensitivity, good response to loud and soft



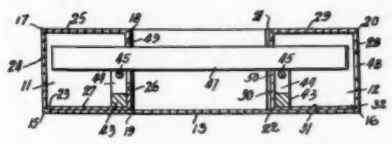
playing, and quick and effective damping obtainable in such piano actions." Apparently hammers with short shanks strike the lower bars **32**, those with long shanks strike the upper bars. Note that the sticker **38** is pivoted at **17.** The entire keybed also is hinged on this same axis, so that it may be folded up when the instrument is not in use, without subjecting the action to any unusual tension. —R. W. Y.

2,317,164

6.4 XYLOPHONE

Harry Zimmerman.
April 20, 1943, 11 Claims (Cl. 84–403).

This patent discloses a construction for a xylophone requiring no metal, which is particularly suited to toy instruments. A single cardboard blank **14** is scored at **15,**



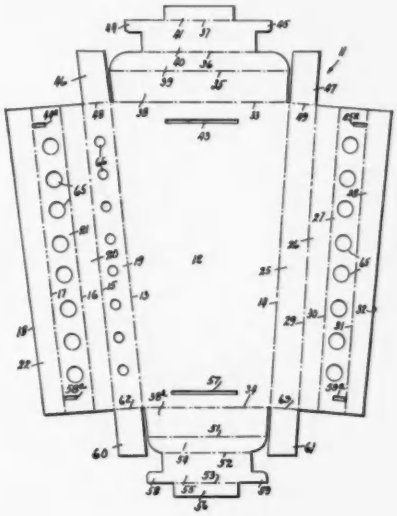
16, 17, 18, 19, 20 so as to permit folds at these lines. The musical bar **47,** which may be of glass, rests on cords **45** stretched along strips **43** from which semicircular spaces **44** have been cut. End blocks suitably grooved to receive the base make the assembly rigid.—R. W. Y.

2,317,165

6.4 XYLOPHONE

Harry Zimmerman.
April 20, 1943, 8 Claims (Cl. 84–403).

The simple structure here disclosed may be used to support a xylophone bar as in Patent 2,317,164. In the present case the end supports are also folded from the



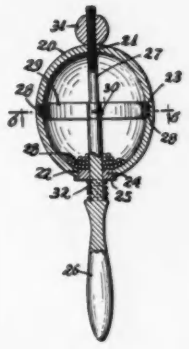
same blank from which the sides are formed. This results in a hollow tubular border around the entire instrument.—R. W. Y.

2,318,460

6.4 MARACA

Samuel Brief.
May 4, 1943, 2 Claims (Cl. 46–193).

A groove **23** containing captured shot **28** makes it possible for this maraca to produce a variety of sounds not



ordinarily available. When the player wishes to remove the shot from this groove he presses on the top of the gourd

20, thereby compressing spring **32.** This uncovers the groove, since the spiral spring **29** is rigidly attached by a pin **30** to the shank **27.**—R. W. Y.

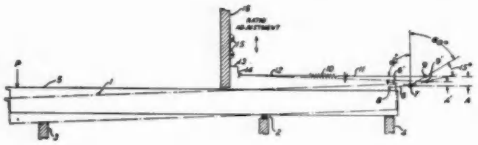
2,309,537

6.5 KEY ACTION MECHANISM

Albert R. Rienstra, assignor to Bell Telephone Laboratories, Incorporated.

January 26, 1943, 2 Claims (Cl. 84–440).

"The Standardization Committee of the American Guild of Organists has specified that the pressure at the front edge of keys be four ounces and two ounces, respectively, for the normal and operated positions." To attain this decrease in the force required as the key of an organ is depressed, according to this invention an intermediate lever **6** is provided with its fulcrum **7** so located that as



the key lever **1** is moved from its position of rest (shown by solid lines), the restoring moment of spring **10** is decreased because of the decrease in effective lever arm from **A** to **A′**. This change in lever arm may be adjusted by shifting the spring support **13.** Spring **10** is made long so that it exerts but slightly greater force in the extended position than in the normal condition.—R. W. Y.

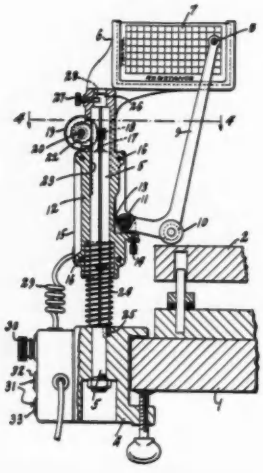
2,311,752

6.6 PIANO KEY ACTION TESTING DEVICE

Josef Hofmann.

February 23, 1943, 7 Claims (Cl. 265–2).

This piano key action testing device affords a means for making a permanent record of the key's "resistance." As



indicated in the figure, a graph is automatically plotted showing the "resistance" to motion relative to the travel of the tip of the key where the finger would normally rest. An electric motor, geared to the rack **23** which is stationary, moves the whole assembly downward including the sleeve **12** and the arm **9.** Although the key **2** is thereby carried down, it reacts against roller **10** and thus causes the lever arm **9** to rotate about pivot **11.** This rotation is a measure of the "resistance" which is recorded graphically by the marking stylus **8.** The vertical travel of the key is recorded at the same time. Having once found an action having the proper touch, one may use this device to facilitate the adjustment of other keys to this standard.—R.W.Y.

Des. 135,692

6.7 VIOLIN

Mathew Little.

May 18, 1943.

In this design for a violin the "bass" bar rests upon the sound post in the center of the body.—R.W.Y.

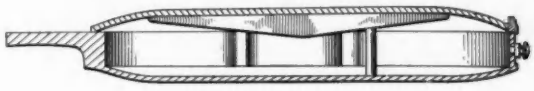


FIG. 1.

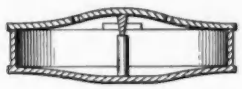


FIG. 2.

2,316,799

6.7 STRINGED MUSICAL INSTRUMENT

John W. McBride.

April 20, 1943, 10 Claims (Cl. 84–315).

The novel means of stopping a string of a stringed instrument, as disclosed in this patent, consists of a rod lying just under and parallel to the string, having a helical ridge. A rack, made part of key **35,** for example, meshing

with a pinion on rod **37** causes it to rotate, thereby moving quickly the point of contact of the helix with the string. The cover **75** may be supplied with a series of marks to assist the player in depressing key **35** the proper amount to produce a sound of desired frequency. In conjunction with electrical amplification a volume control is arranged to be

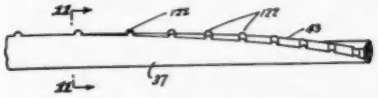
operated by a thumb button **107**, this being in a convenient position when the instrument is held in the lap. An alternate lever is available when the instrument is played with the hand below the mechanism.—R.W.Y.

2,316,800

6.7 STRINGED MUSICAL INSTRUMENT

John W. McBride.
April 20, 1943, 10 Claims (Cl. 84–315).

After the manner disclosed in patent 2,316,799, a rod with a helical crest is arranged to determine the free length of a vibrating string, without the necessity of materially



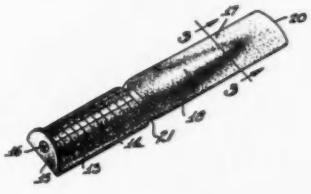
shifting the position of the hand. In the present invention the crest is furnished with "teeth" spaced according to the positions of the usual frets. This results in discrete frequency steps so that the exact rotation of rod **37** is not extremely critical. The teeth are situated at equal angular distances so that equal movements of the key **35** produce equal musical intervals regardless of the length of string vibrating.—R.W.Y.

2,318,515

6.8 REED

Jasper C. Nemcek, Jr.
May 4, 1943, I Claim (Cl. 84–383).

The upturned end **15** and the corrugated surface **14** of this reed for a musical instrument, such as a saxaphone, are



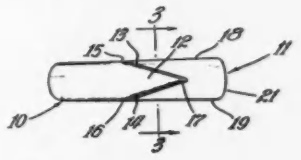
intended to assist in keeping the ligature in position. The flexibility of the reed, which is preferably made of a plastic, may be adjusted to fit an individual player's wishes by filing the groove **21** still deeper or by thinning the longitudinal web **18**. The hole **16** is intended for convenience in suspending the reed in a sterilizing solution.—R.W.Y.

2,319,419

6.8 REED

Stephen J. Lucas.
May 18, 1943, 2 Claims (Cl. 84–383).

"Claim 2. A wood-wind reed comprising an elongated body portion with a vibrating tongue portion at one end therof, said vibrating tongue portion having a heart extending lengthwise of the center thereof from the body portion toward the free end of the tongue, said heart being thicker and more rigid than the tongue portion and having



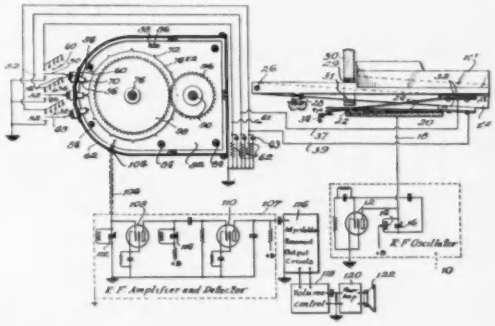
opposite side edges defined by grooves extending in converging lines to an apex at the end of said heart toward the free end of the vibrating tongue portion, said vibrating tongue having the side portions of the top surface thereof on opposite sides of said heart tapering downwardly from said grooves to thin opposite edges and said tongue portion tapering lengthwise to a thin end edge."—R.W.Y.

2,314,496

6.9 ELECTRICAL MUSICAL INSTRUMENT

Laurens Hammond.
March 23, 1943, 20 Claims (Cl. 84–1.23).

"In general, the instrument comprises a tunable radio frequency oscillator which supplies a carrier wave to a key controlled variable condenser of unique construction, the



radio frequency carrier wave passing through this condenser upon operation of the key, to be modulated by passing through a circuit having a capacity varied by a rotating tone wheel. The modulated carrier wave thus produced is demodulated, amplified, and translated into sound. One of the distinctive features of the invention is that all of the rotary modulators, or tone wheels, rotate at speeds near seven revolutions per second, so that any irregularities in the tone wheel form will result in introducing vibrato frequencies rather than dissonant and noise frequencies." The irregularities may be those inherent in ordinary manufacture, or they may be introduced by such means as varying the spacing or shape of teeth **72** or causing the speed to fluctuate within each revolution of the tone wheel.—R.W.Y.

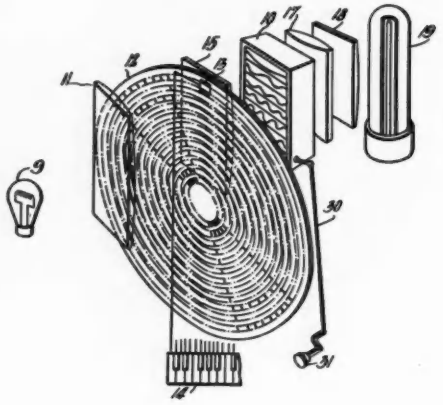
2,318,144

6.9 PHOTOELECTRIC MUSICAL INSTRUMENT

Francis J. Darke, Jr., assignor to Radio Corporation of America.

May 4, 1943, 8 Claims (Cl. 84–1.18).

"Claim 2. Tone control mechanism for an electric musical instrument of the type wherein a moving beam of light scans a stationary wave image and is thereafter directed to a photoelectric cell including a plurality of variable area wave image shutters to produce different tones, and means for selectively adjusting each of said shutters about the base line of the image to intercept a greater or smaller proportion of the light beam to vary the amplitude of each respective tone, the greater the amount of light transmitted to said cell, the smaller the degree of modulation of said



light beam and the amplitude of each respective tone." The shutters may be brought to the desired adjustment by draw stop **31** connected through pull rod **30.**—R.W.Y.

2,318,935

6.9 ELECTROSTATIC ALTERNATOR

Raymond C. Fisher.

May 11, 1943, 17 Claims (Cl. 175–363).

This patent teaches how electrodes in the form of sectors of a circle may be arranged in an electrostatic alternator to produce wave forms suitable for musical purposes. For example, the figures reproduced here show a stator and rotor, respectively, designed to produce nearly sinusoidal changes of capacitance at four frequencies related by octaves. The lands are designated by **a,** the indentations by **b.** In track **2** of the stator there are 2 lands each of 60 degrees and 2 indentations each of 120 degrees. The corresponding track **102** on the rotor is equally divided into 90-degree lands and indentations. The dimensions assigned to the stator are responsible for the suppression of third harmonic and multiples thereof; the rotor dimensions suppress even numbered harmonics. An electrically conductive coating is applied to the electrodes to minimize residual charges which would tend to keep the alternator operative after the polarizing voltage has been removed. A trap electrode is placed between the active electrodes to remove leakage currents which tend to flow through the insulating supports.—R.W.Y.

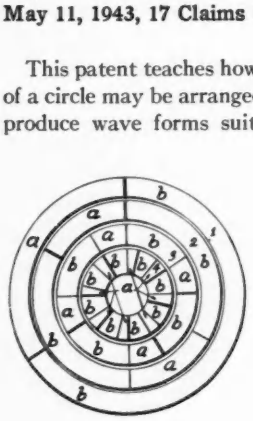


FIG. 1.

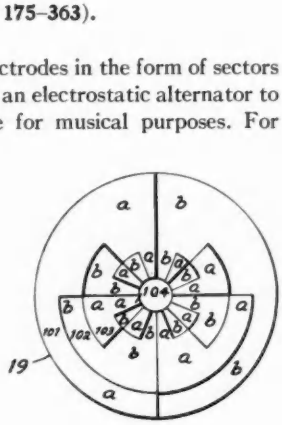


FIG. 2.

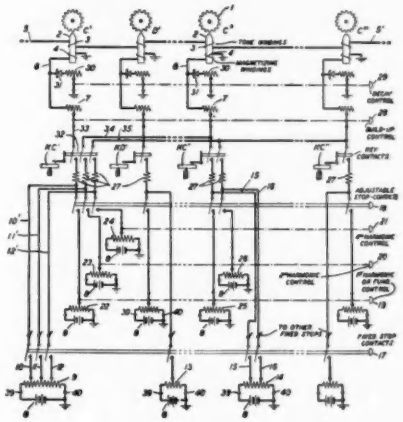
2,319,087

6.9 ELECTRIC ORGAN KEYING SYSTEM

Albert R. Rienstra, assignor to Bell Telephone Laboratories, Incorporated.

May 11, 1943, 7 Claims (Cl. 84–1.26).

This keying system makes it possible to control the build-up and decay rate in an electronic musical instrument such as the type which employs toothed wheel electromagnetic generators. The windings **3** for the various tones are connected in series. The low retentivity pole pieces **2** also carry field windings **4.** An appropriate voltage may be



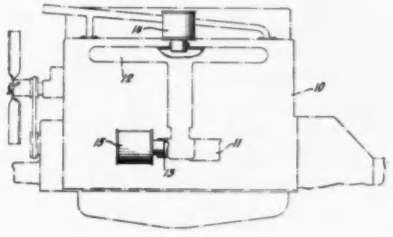
set up by stop contact **17,** so that when key switch **32,** for example, is depressed a current flows in selected field windings at a rate dependent upon the resistance **7** adjusted by the build-up control **28.** When switch **32** is opened the rectifier **31** permits the field current to decay at a rate dependent upon the setting of resistor **30.** Controls **19, 20, 21** make it possible to adjust independently the strength of each partial in a complex tone.—R.W.Y.

2,325,352

7.7 RESONATOR SILENCER

Ernest E. Wilson, assignor to General Motors Corporation.
July 27, 1943, 22 Claims (Cl. 181–48).

In an intake system of an internal combustion engine, attenuating silencers are connected as a side branch. —C.E.N.

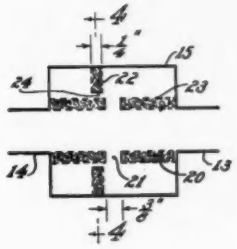


2,326,612

7.7 SILENCER

Roland B. Bourne, assignor to The Maxim Silencer Company.
August 10, 1943, 21 Claims (Cl. 181–48).

This patent is an extension of an earlier patent 2,043,731 and refers to the type of silencer construction in which the main conduit is lined with a sound absorbent material. An



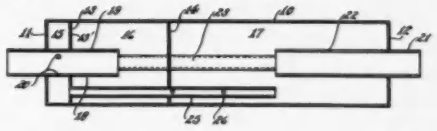
outer or resonator chamber is coupled to the inner tube through a gap entrance and through the sound absorbent material or combinations of these couplings. Correct density of the absorbent material is found to be one of the critical factors in efficient operation.—C.E.N.

2,326,613

7.7 SILENCER

Roland B. Bourne and John P. Tyskewicz, assignors to The Maxim Silencer Company.
August 10, 1943, 7 Claims (Cl. 181–53).

This patent is a modification of an earlier patent 2,264,195 which described the general construction common to both patents. In this construction three or more chambers are used with a system of parallel paths for the gas flow. In the figure shown herewith the auxiliary path



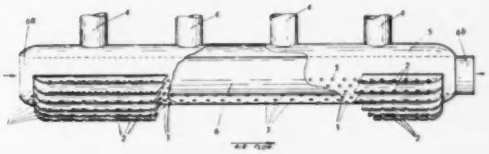
consists of tube **25** whereas the main gas flow is handled by tubes **23.** It is claimed that this construction results in improved silencing and lower backpressure.—C.E.N.

2,323,891

7.7 SILENCER

Joseph George Blanchard, assignor of one-half to Cecil Gordon Vokes.
July 13, 1943, 4 Claims (Cl. 181–60).

This type of muffler is intended for use on fast moving vehicles such as aircraft and is designed so that the exhaust gas is released at the end of a "corrugation" or "ridge."



These "ridges" are arranged in the direction of flow so as to provide large cooling surfaces and release the gas at a point of reduced pressure.—C.E.N.